Message

Sent: 12/14/2018 5:42:57 PM
To: Harrison, David [David.Harrison@NERA.com]
CC: CNevers@autoalliance.org
Subject: A second question on the NERA study

David,

My staff and I had another question regarding the NERA study on the SAFE NPRM done for the Auto Alliance.

We are trying to understand why the NERA study estimated in the net societal benefits for fuel savings is so much lower then what was projected in the Notice of Proposed Rulemaking. In the NPRM, NHTSA estimated the pre-tax fuel savings for society for the proposal to be over $100 billion. In the NERA report, the valuation is $51.3 billion with a 3% discount rate and $38.0 billion with a 7% discount rate (shown in Table 40 on page 55)

On page 55 of the NERA report, under Section B., there is the following statement:

"Our methodology for estimating the benefit consumers receive from the improved fuel efficiency includes changes in consumers' valuation of prospective fuel savings from improvements"."

From: Charmley, William
Sent: Friday, November 30, 2018 3:55 PM
To: Harrison, David <David.Harrison@NERA.com>
Subject: RE: Question on the NERA study

David –

Thanks for getting back to me, I appreciate it.

Best regards,
Bill

From: Harrison, David <David.Harrison@NERA.com>
Sent: Friday, November 30, 2018 10:15 AM
To: Charmley, William <charmley.william@epa.gov>
Cc: Chris Nevers <CNevers@autoalliance.org>
Subject: RE: Question on the NERA study

Hi Bill,

Good to hear from you. The gasoline price projections we used are from AEO 2017, based upon the information in the CAFE model.

Please give my best to others in Ann Arbor.

Best,

== Dave

David Harrison, Ph.D., Managing Director
NERA
ECONOMIC CONSULTING
Tel: +1 617 927 4512
david.harrison@nera.com

From: Charmley, William <charmley.william@epa.gov>
Sent: Thursday, November 29, 2018 4:36 PM
To: Harrison, David <David.Harrison@NERA.com>
Cc: Chris Nevers <CNevers@autoalliance.org>
Subject: Question on the NERA study

Dear David –

I hope all is going well with you and your colleagues out in Cambridge.

My staff were reviewing with me today the NERA report conducted for the Auto Alliance "Evaluation of Alternative Passenger Car and Light Truck Corporate Average Fuel Economy (CAFE) Standards for Model Years 2021-2026" which was submitted by the Alliance as part of their comments on the recent DOT/EPA proposal for fuel economy and GHG standards for light-duty vehicles.

At this point I we have one clarifying question that I am hoping you can answer for us, and that it, what gasoline fuel price projections did NERA use for the NERA analysis? In particular, in the Table 48 Net Benefits projections on page 61, which fuel price projection forecast was used? This is the same information presented in Table ES-3 in the Executive Summary.

We see discussion in the report of EIA's AEO 2017 projections, and also the 2018 IHS Markit Retail Gasoline Price Forecast. Were one of these used in the NERA modeling to detailed in the report, and in particular the analysis presented in the Tables ES-3 and Table 48?

Thank you for your help on this.

Best regards,
Bill

Bill Charmley
Director
Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

National Vehicle and Fuel Emissions Laboratory
2000 Traverwood Drive
Ann Arbor, MI 48105

desk ph. 734-214-4466
cell ph.   734-545-0333
e-mail: charmley.william@epa.gov

Message

Sent: 11/29/2018 9:29:13 PM
To: David Harrison (david.harrison@nera.com) [david.harrison@nera.com]
CC: Chris Nevers [CNevers@autoalliance.org]
Subject: Question on the NERA study
Attachments: Attachment 1 NERA Evaluation of Alternative Passenger Car and Light Duty Truck CAFE Standards.pdf

Dear David –

I hope all is going well with you and your colleagues out in Cambridge.

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We see

Bill Charmley
Director
Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

National Vehicle and Fuel Emissions Laboratory
2000 Traverwood Drive
Ann Arbor, MI 48105

desk ph. 734-214-4466
cell ph. 734-545-0333
e-mail: charmley.william@epa.gov

Evaluation of Alternative Passenger Car and Light Truck Corporate Average Fuel Economy (CAFE) Standards for Model Years 2021-2026

Prepared for the Alliance of Automobile Manufacturers

October 26, 2018

Project Team

<u>NERA Economic Consulting</u>
David Harrison, Ph.D., Project Director
Andrew Busey
Eli Shakun
Katya Dajani
Charles Kuchenbrod

<u>Trinity Consultants</u>
James Lyons, Project Director
Thomas Carlson
Jonathan Snoeberger

<u>Project Directors</u>

Dr. David Harrison is a Managing Director and co-chair of NERA's global environmental economics practice. He has been active in the development and assessment of climate change and other major energy and environmental policies around the world as a consultant to numerous private and public groups. Before joining NERA, Dr. Harrison was an Associate Professor at Harvard's Kennedy School of Government and on the senior staff at the President's Council of Economic Advisors. He received a Ph.D. in economics from Harvard University, a M.Sc. in economics from the London School of Economics and a B.A. in economics from Harvard College.

Mr. James Lyons is a Principal Consultant at Trinity Consultants, Inc. He has extensive experience assessing the benefits, costs and cost-effectiveness of new vehicle emission standards for criteria pollutants, greenhouse gases, and fuel economy. Mr. Lyons was previously a Senior Partner at Sierra Research, Inc., and he began his career at the California Air Resources Board.

NERA Economic Consulting
11th Floor, 200 Clarendon Street
Boston, Massachusetts 02116
Tel: +1 617 927 4500
www.nera.com

Trinity Consultants
3301 C Street, Suite 400
Sacramento, CA 95816
Tel: + 1 916 444-6666
www.trinityconsultants.com

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Executive Summary

This report evaluates the effects of alternative Corporate Average Fuel Economy (CAFE) standards for passenger cars and light trucks (collectively "vehicles") for model year (MY) 2021 to MY 2026, developing results for three of the eight alternatives that were evaluated recently by the National Highway Traffic and Safety Administration (NHTSA) and the U.S. Environmental Protection Agency (EPA).[1] The evaluations are based upon a suite of models including ones developed by government agencies as well as ones developed by NERA Economic Consulting (NERA) and Trinity Consultants (Trinity). Our evaluations include estimates of the market impacts of alternative CAFE standards, including effects on new motor vehicle sales, on scrappage rates for existing vehicles, and on vehicle miles traveled (VMT). We use estimates of these market effects combined with other information to develop estimates of the social costs and social benefits of alternative CAFE standards, with resulting estimates of the net benefits for each of the alternatives.

A. Background

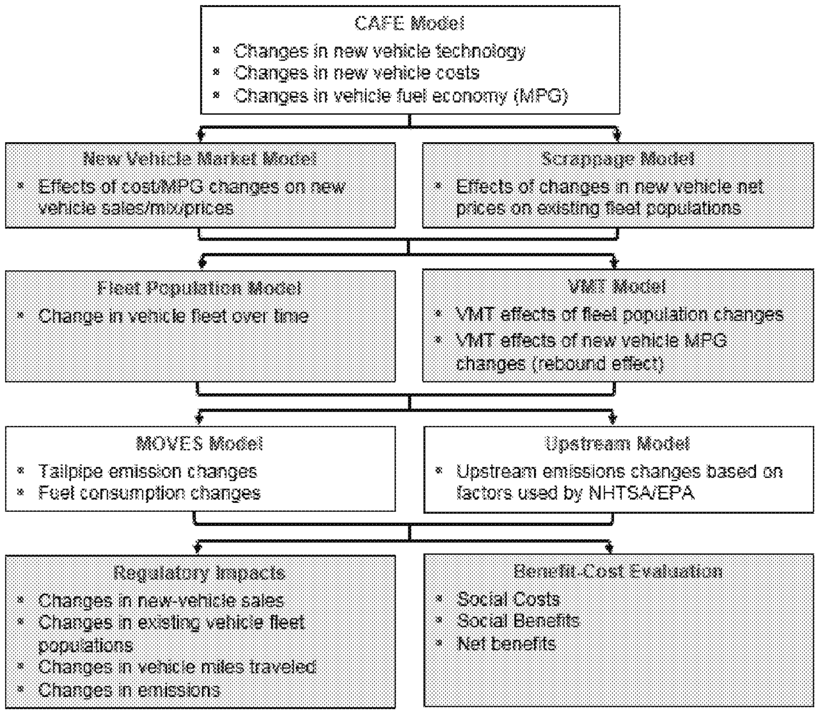
1. Modeling Framework

The modeling framework we use allows us to estimate the impacts of alternative CAFE standards on the motor vehicle fleet—including changes in new vehicle sales and changes in the scrappage of existing vehicles—as well as on VMT over the analysis period, which is from 2017 to 2050. Results are developed for light-duty vehicles for model years through MY 2029.[2] Figure ES-1 provides an overview of the framework, showing the models used and their interactions.

[1] The three alternatives we evaluate bracket the stringency range of CAFE standards evaluated by NHTSA and EPA. Note that NHTSA and EPA also evaluated standards for carbon dioxide (CO_2) emissions for the same model years. We estimate effects of the alternative CAFE standards and do not develop separate estimates for alternative CO_2 standards. Since the two sets of standards are harmonized, however, our comparative results for the alternative CAFE standards should apply to the equivalent CO_2 standards (although the specific estimates would differ).

[2] The analyses developed by NHTSA and EPA provide results of alternative MY 2021-MY 2026 standards for model years beyond MY 2026; following their analyses, we present results for changes through MY 2029.

Figure ES-1. Model Structure



The following are brief overviews of these models.

- *CAFE Model.* The CAFE Model, developed by the Department of Transportation (DOT) and implemented by Trinity, provides detailed information on the light-duty vehicle fleet, consisting of detailed motor vehicle model/configurations for MY 2016 and projections for model years after 2016. Trinity uses the CAFE Model to estimate the effects of the three CAFE alternatives on motor vehicle costs and fuel economy for the detailed vehicle categories included in the CAFE Model.

- *New Vehicle Market Model.* The New Vehicle Market Model, developed by NERA, provides estimates of the effects of the regulatory alternatives on new vehicle prices and sales, based upon the compliance costs and fuel economy changes predicted in the CAFE Model. The estimated net changes in new vehicle prices reflect the costs to comply with the CAFE standards minus the value that new vehicle purchasers place on the changes in fuel economy, values that are developed as part of the New Vehicle Market Model.

- *Scrappage Model.* The Scrappage Model, developed by NERA, provides estimates of the changes in scrappage of existing vehicles (by vehicle age) due to the changes in new vehicle net prices.

- *Fleet Population Model.* The Fleet Population Model, developed by NERA and Trinity, keeps track of changes in the light-duty vehicle fleet over the analysis period (2017-2050), including information on the numbers of vehicles of different ages in each calendar year. Thus, for example, the fleet population model provides information on the number of passenger cars in 2030 in different age groups (e.g., new, 1-year old, 2-year old, etc.).

- *VMT Model.* This model, developed by NERA and Trinity, includes the effects of changes in VMT due to the alternative CAFE standards, including changes due to changes in the age profile of the fleet (reflecting lower VMT from older vehicles) as well as changes due to the well-recognized "rebound effect," i.e., the effect of changes in fuel efficiency on the cost per mile of driving and thus (via a price/demand effect) on the number of miles driven.
- *MOVES Model.* The MOVES Model, developed by EPA and implemented by Trinity, provides baseline information on the motor vehicle fleet and VMT and related values for emissions. Trinity uses MOVES to develop estimates of changes in vehicle tailpipe emissions due to the three alternative CAFE standards, accounting for changes in the age of the fleet as well as changes in VMT. The model includes results for greenhouse gas emissions, as well as emissions for five criteria pollutants.
- *Upstream Model.* The MOVES Model does not include estimates of changes in upstream emissions (e.g., refinery emissions due to changes in gasoline production). An Upstream Model is developed based on the upstream emissions factors used by NHTSA/EPA in the PRIA, which are based on the GREET Model developed by Argonne National Laboratory.

The figure does not show the many other parameters used in this study to develop estimates of social costs and social benefits of alternative CAFE standards, many of which are based upon information developed by NHTSA and EPA; information on these parameters is provided in the body of the report and in appendices.

2. Alternative CAFE Standards Evaluated

In the Preliminary Regulatory Impact Analysis (PRIA), NHTSA and EPA evaluated eight alternatives, all relative to the current set of standards (which is the "no action" alternative). This no action alternative assumes that the MY 2021 standards remain in place, that the MY 2022-2025 augural CAFE standards are finalized and that MY 2026 standards are set at MY 2025 levels.[3] For ease of exposition, we refer to the MY 2021 to MY 2026 standards in this baseline scenario as the "augural standards baseline." We evaluated three of these eight standards, as summarized in Table ES-1. The three alternatives we evaluated correspond to Alternative 1, Alternative 5, and Alternative 8 in the NHTSA/EPA PRIA. The alternatives are numbered in terms of stringency, so that Alternative 1 is the least stringent and Alternative 8 is the most stringent alternative (other than the augural standards baseline, which is the most stringent). The three CAFE alternatives evaluated in this report were chosen to provide an analysis that encompasses the same range in stringency as in all eight of the alternatives evaluated in the PRIA.

[3] See e.g., Table I-4 of the NHTSA/EPA NPRM (2018a).

Table ES-1. CAFE Regulatory Alternatives

Alternative	Change in stringency
Baseline/ No-Action ("Augural")	MY 2021 standards remain in place; MYs 2022-2025 augural CAFE standards are finalized; MY 2026 standards are set at MY 2025 levels
8	Existing standards through MY 2021, then 2%/year increases for passenger cars and 3%/year increases for light trucks, for MYs 2022-2026
5	Existing standards through MY 2021, then 1%/year increases for passenger cars and 2%/year increases for light trucks, for MYs 2022-2026
1	Existing standards through MY 2020, then 0%/year increases for both passenger cars and light trucks, for MYs 2021-2026

Note: These alternatives assume no changes in treatment of air conditioning efficiency or off-cycle provisions.

Since these standards are footprint-based, the actual miles-per-gallon (MPG) CAFE requirements will vary by automobile manufacturer and will depend on the sales mix of manufacturers' vehicles. To provide an illustration of how the standards differ across scenarios, Table ES-2 provides the average MPG requirements as estimated in the CAFE Model for model years 2021-2026.

Table ES-2. Average CAFE Estimated Requirements by Regulatory Scenario (Passenger Cars and Light Trucks), MY 2021-2026

	Model Year					
Scenario	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**
Augural Stds.	38.9	40.7	42.7	44.7	46.8	46.8
8	38.9	39.9	40.9	42.0	43.1	44.2
5	38.9	39.5	40.1	40.7	41.4	42.0
1	36.9	36.9	36.9	36.9	36.9	36.9

Note: Values represent the estimated combined (i.e., passenger cars and light trucks) light-duty vehicle CAFE MPG requirement. As described in the text, the actual MPG requirements are different for cars and for light trucks and differ also for the various automobile manufacturer depending on each manufacturer's sales mix. The values in Table ES-2 represent average MPG requirement estimates based on sales and MPG values in the CAFE Model for the relevant model years.

Since the augural standards are more stringent than the three alternatives, the results we develop are generally estimates of the *reductions* in social costs and the *reductions* in social benefits due to the three less-stringent CAFE standards. The net benefits of each standard depend upon the relationship of the two reduced values; if the reduction in social costs is greater than the reduction in social benefits, the standard is estimated to lead to a net gain in social welfare (as measured by social benefits and costs); if the reduction in social costs is less than the reduction in social benefits, the standard would lead to a net loss in social welfare.

B. Motor Vehicle Market Impacts

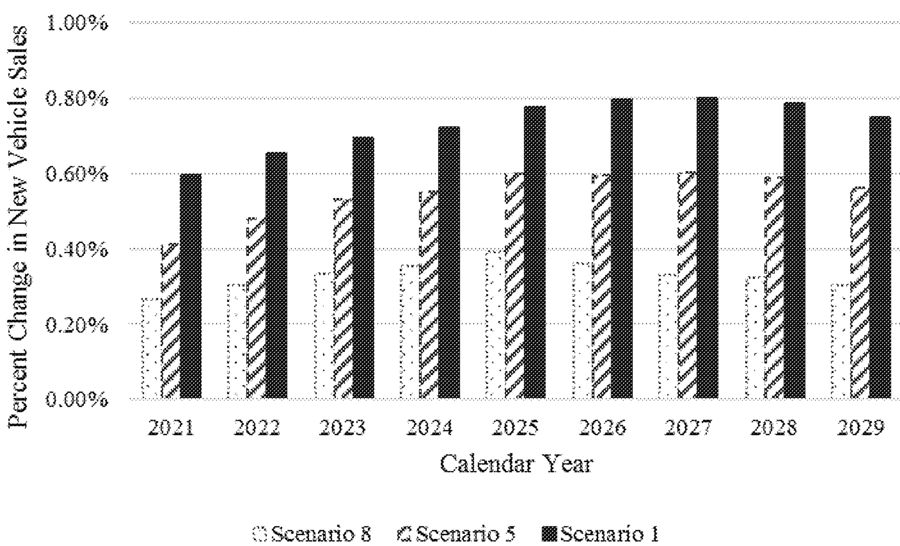
Implementation of the CAFE alternatives would lead to changes for the vehicle fleet, including changes in the age composition of the fleet as well as changes in VMT.

1. Changes in the Vehicle Fleet

a. New Vehicle Sales

The alternative CAFE standards affect new vehicle sales by changing the prices and fuel economy of the new vehicles that are offered for sale and, due to the operation of the market for new vehicles, the number of new vehicles that are sold. Figure ES-2 shows the percentage change in sales by model year for the three alternative CAFE standards as compared to the level of sales under the augural standards. These changes in new vehicle sales reflect the net effects of the decreases in prices and the decreases in in fuel economy (MPG) due to the less-stringent alternative CAFE standards. The alternative CAFE standards are projected to lead to greater new vehicle sales, with the percentage increase varying over the various model years.

Figure ES-2. Differences in New Vehicle Sales Compared to Augural Standards Baseline, MY 2021-2029



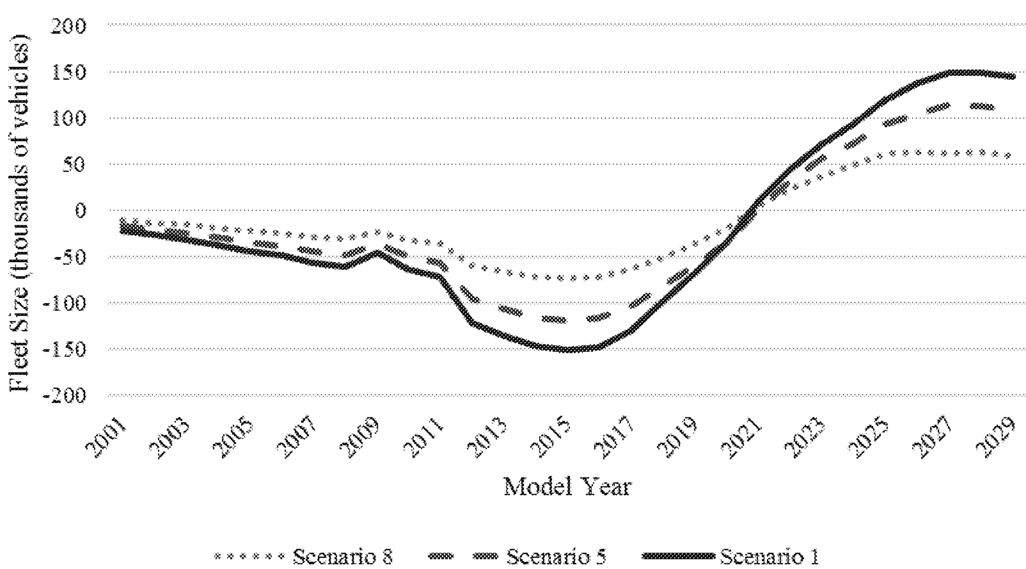
b. Existing Vehicle Scrappage

These changes in new vehicle prices and the values placed on changes in fuel economy are used to estimate a "net" new vehicle price change for each model year, i.e., a percentage increase in new vehicle price that reflects changes in the quality of the new vehicles as measured by changes in MPG. These changes in the "net" prices for new vehicles lead to changes in the existing fleet because new vehicles and existing vehicles are substitutes for one another. Price increases for new vehicles thus would lead to increases in the number of older vehicles (obtained via reduced scrappage of existing vehicles); in the same manner, price decreases for new vehicles will lead to decreases in the number of older vehicles (obtained via increased scrappage of existing vehicles). The net effect of the three alternative CAFE standards thus is to change the age distribution of the vehicle fleet in any given calendar year from that under the augural standards.

c. Age Distribution of the Vehicle Fleet

Figure ES-3 provides an illustration of the fleet effects of the three alternative CAFE standards we evaluate. For a given calendar year, in this case 2030, the figure shows the changes in the number of light-duty vehicles by age due to the three standards. These results show the following expected patterns: (a) sales of new vehicles subject to the CAFE standards increase for the three alternatives (i.e., the less-stringent standards lead to larger sales); and (b) numbers of existing vehicles decrease (i.e., the lower prices for newer vehicles lead to lower prices for existing vehicles and thus more scrappage of existing vehicles). For scale, the estimated fleet size in 2030 is 251 million vehicles under the augural standards. The combined fleet effects under Alternative 1 combine to produce a fleet that includes 0.65 million fewer light-duty vehicles in 2030, reflecting the difference between the increases in new vehicle sales and the decreases in existing vehicles. This difference represents a 0.2 percent change in fleet size relative to the augural standards baseline.

Figure ES-3. Differences in Fleet Effects Compared to Augural Standards Baseline by Model Year, for Calendar Year 2030



2. Changes in Vehicle Miles Traveled

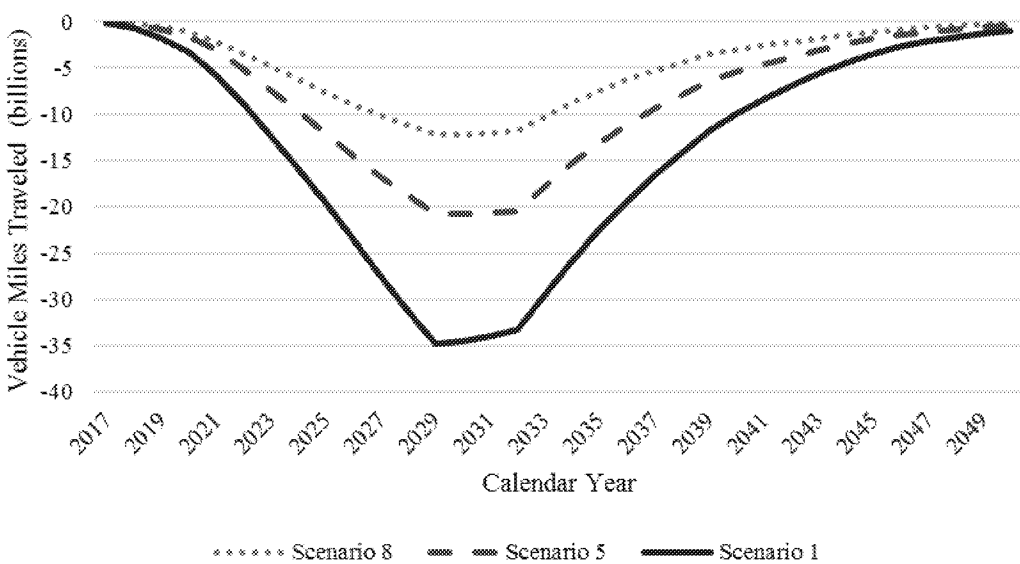
The alternative CAFE standards affect VMT in two ways.

- *Age distribution effects*. Because older vehicles are driven less than newer vehicles, a shift in the age distribution of the fleet would lead to changes in the number of miles traveled.
- *Rebound effects.* Changes to vehicle fuel economy due to the standards would lead to changes in the number of miles traveled for vehicles subject to the standards. Any change

in fuel economy would affect the cost per mile driven and thus (via a demand effect) the number of miles traveled; this is often referred to as the “rebound effect.”

Figure ES-4 provides estimates of the effects on VMT of the three alternative CAFE standards relative to the augural standards, showing results for vehicles in the model years covered by our analyses (i.e., up to MY 2029) over the period covered by our analysis (2017 to 2050). Annual VMT is lower for all three alternatives, reflecting the rebound effect (i.e., lower MPG of the new vehicles lead to an increase in the cost/mile and thus a decrease in the number of miles traveled). For scale, estimated total VMT of light-duty vehicles in 2029 is 3.05 trillion miles under the augural standards—thus the 35-billion-mile reduction in VMT under Scenario 1 represents a 1.1 percent reduction.

Figure ES-4. Differences in VMT Compared to Augural Standards Baseline by Calendar Year

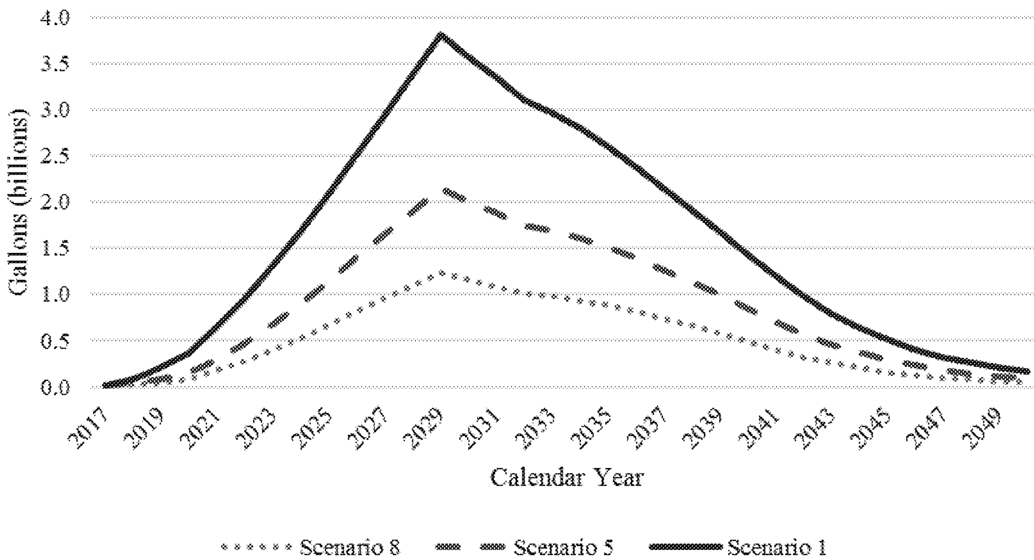


Note that because we include vehicles only up to and including MY 2029, the changes due to the three alternative standards decrease over time as more of the MY 2029 and earlier vehicles are scrapped. By the end of the period (2050), even the “newest” MY 2029 vehicles are 21 years old. This same pattern is evident in all graphs showing effects by calendar year.

3. Changes in Fuel Consumption

The alternative CAFE standards affect motor fuel consumption through effects on the fuel economy of the new vehicles, on the age composition of the vehicle fleet, on the vehicle type mix of the vehicle fleet (i.e., light trucks vs passenger cars) and on the VMT of the fleet. Figure ES-5 provides estimates of the motor fuel consumption (cumulative for gasoline, diesel, and E85) of the three alternative CAFE standards over the analysis period. Estimated fuel consumption increases for all three alternatives relative to the levels under the augural standards, reflecting the lower average MPG of the fleet (an effect that outweighs the effects of fewer VMT). In 2029, estimated light-duty vehicle fuel consumption is 98 billion gallons under the augural standards—thus the 3.8-billion-gallon increase under Scenario 1 represents a 3.9 percent change. Among all uses of motor gasoline and diesel, which are projected to total 166 billion gallons in Annual Energy Outlook 2018 (EIA AEO 2018), this would represent a 1.3 percent change.

Figure ES-5. Differences in Motor Fuel Consumption Compared to Augural Standards Baseline by Calendar Year



Note: Gallon values include gasoline, diesel, and E85 fuel consumption.

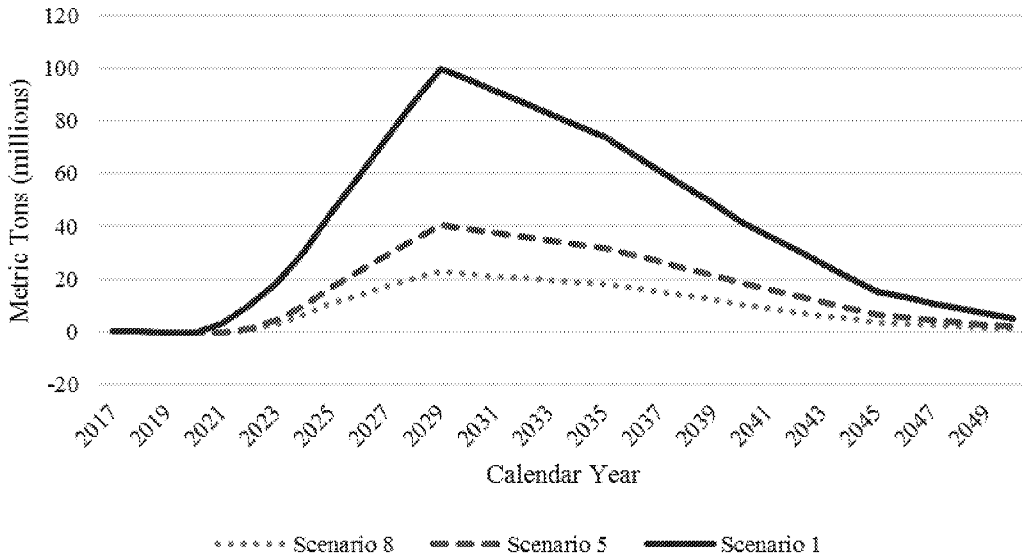
4. Changes in Emissions

The alternative CAFE standards affect tailpipe emissions through changes in the age composition of the fleet and changes in VMT. In addition, changes in fuel use lead to changes in upstream emissions (e.g., refinery emissions). Our modeling includes two general classes of emissions: (a) Greenhouse gas (GHG) emissions, including CO_2 and the other emissions that contribute to overall GHG emissions; and (b) criteria pollutants, which include emissions that affect ambient air quality, either directly or as precursors.

a. Greenhouse Gas Emissions

Figure ES-6 provides estimates of the change in GHG emissions (expressed as CO_2 equivalents) of the three alternative CAFE standards we evaluate over the period covered by our analysis. The GHG emissions increase for all three alternatives relative to the augural standards, reflecting the increase in fuel consumption due to the less fuel-efficient fleets under the less-stringent standards. In 2029, estimated total CO_{2eq} emissions for the light-duty fleet are 1.1 billion metric tons; thus the 99.7 million metric ton increase under Scenario 1 represents an 9.1 percent change in light-duty fleet emissions.

Figure ES-6. Differences in GHG Emissions (CO_{2eq}) relative to Augural Standards Baseline by Calendar Year

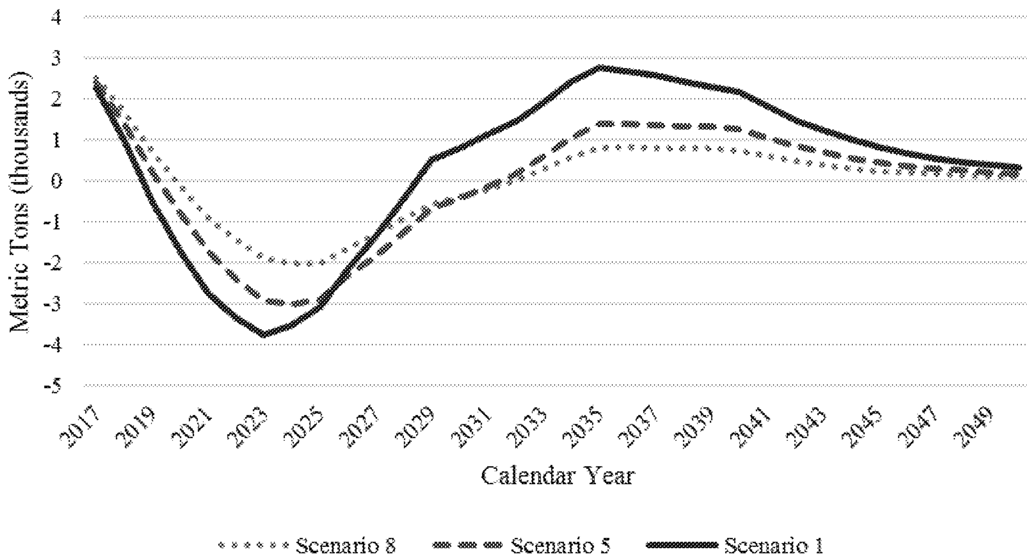


Note: GHG emissions presented as CO_2 equivalents and include CO_2, N_2O, and CH_4 emissions.

b. Criteria Pollutant Emissions

Figure 8 provides estimates of the changes in NO_X emissions—one of the major criteria pollutants affected by the CAFE alternatives—due to the three alternative CAFE standards. (Results for the other pollutants are presented in the report.) The changes in NO_x emissions are due both to changes in tailpipe emissions and changes in upstream emissions. Tailpipe emissions of NOx are lower for all three alternatives relative to the augural standards baseline, reflecting the accelerated scrappage of older vehicles under the less-stringent standards. In contrast, upstream emissions of NOx increase relative to the augural standards because of increases in demand for motor fuel, based on the agencies' current analysis, which we adopt for purposes of this study. The net effect results in changes in NO_X emissions relative to the augural standards baseline that are generally lower in the early years (as tailpipe emissions reductions exceed upstream emissions increases) and generally higher in the later years (as upstream emissions increases exceed tailpipe emissions reductions) under the alternative CAFE standards. As with all effects, by the end of the period the net changes are small because MY 2029 and earlier motor vehicles become a small part of the vehicle fleet.

Figure ES-7. Differences in NO_X Emissions relative to Augural Standards Baseline by Calendar Year



C. Social Costs and Social Benefits

1. Categories of Social Costs and Social Benefits

The modeling framework outlined above allows us to develop estimates of the social costs and social benefits of the three alternative CAFE standards. Our identification of social cost and social benefit categories draws on the framework developed in the PRIA. We include the following four major social cost categories.

1. *New vehicle technology costs.* These costs include the costs of the technologies to achieve compliance with the various CAFE standards.
2. *Congestion costs.* Changes in VMT lead to changes in the congestion costs that motorists incur on the road.
3. *Noise costs.* Changes in VMT lead to changes in the noise levels that motorists experience.
4. *Crash costs.* Changes in the vehicle fleet and VMT lead to changes in fatal and non-fatal crash costs.

We include the following five major social benefits categories.

1. *Fuel economy benefits.* Improvements in new vehicle fuel economy allow drivers to consume less fuel per mile driven, leading to lower fuel expenditures, more VMT (due to the lower cost per mile, i.e., rebound effect), and less time spent refueling.

2. *Fuel tax revenue benefits.* Changes in fuel expenditures lead to changes in tax revenue collected from motor fuel sales. Note that fuel tax payments are part of consumer fuel expenditures, which are a component of consumers' valuation of fuel economy changes.

3. *Petroleum market externality benefits.* Changes in gasoline demand lead to changes in the market price of petroleum and thus have an external effect beyond the effects experienced by new vehicle purchasers.

4. *Greenhouse gas (GHG) emissions benefits.* Changes in VMT, changes in the vehicle fleet, and changes in fuel use affect the levels of CO_2 and other GHG emissions.

5. *Criteria pollutant emissions benefits.* Changes in VMT, changes in the vehicle fleet, and changes in fuel use also affect the levels of criteria pollutant emissions. We calculate dollar estimates for four criteria pollutants, including NOx, VOC, PM, and SO_2.

2. Net Benefit Results

Table ES-3 shows the social costs, social benefits and net benefits of the three CAFE alternatives relative to the augural standards using a 3 percent discount rate; results using a 7 percent discount rate are provided in Table ES-4. The values include effects for model year vehicles up to MY 2029 based on impacts in calendar years from 2017 to 2050. Because the baseline ("no action" alternative) is the most stringent set of standards (augural standards), as noted above, the values for social costs for the three less-stringent CAFE standards evaluated are all negative, i.e., the values show the cost savings from less-stringent standards. Similarly, because the baseline is the most stringent standard, the values for social benefits for the three less-stringent CAFE standards also are generally negative, i.e., most categories show reductions in benefits from setting less-stringent standards. The exceptions are government fuel tax revenue (which is greater due to increased fuel use under Scenarios 8, 5, and 1), and two of the four criteria pollutants (in which reductions in tailpipe emissions essentially cancel out increases in upstream emissions, leading virtually no net change in benefits).

Table ES-3. Net Benefits Relative to Augural Standards Baseline, 3% Discount Rate (billions of 2016$)

	Scenario 8	Scenario 5	Scenario 1
Social Costs			
Technology Costs	-68.8	-113.9	-170.7
Congestion Costs	-6.3	-10.6	-17.9
Noise Costs	-0.1	-0.2	-0.3
Fatal Crash Costs	-1.1	-1.3	-1.0
Non-Fatal Crash Costs	-1.5	-1.7	-1.3
Total Social Costs	**-77.7**	**-127.7**	**-191.2**
Social Benefits			
Valuation of Fuel Economy Benefits	-28.0	-49.0	-87.2
Fuel Tax Revenue Benefits	4.3	7.4	13.2
Petroleum Market Externality Benefits	-1.3	-2.2	-3.9
GHG Damage Reduction Benefits	-1.6	-2.9	-7.1
NO_x Damage Reduction Benefits	0.0	0.1	0.0
VOC Damage Reduction Benefits	0.0	-0.1	-0.1
$PM_{2.5}$ Damage Reduction Benefits	-0.4	-0.8	-1.7
SO_2 Damage Reduction Benefits	-2.0	-3.4	-6.1
Total Social Benefits	**-29.0**	**-50.9**	**-93.0**
Net Total Benefits	**48.7**	**76.8**	**98.2**

Note: Present values calculated as of January 1, 2017 using a 3 percent discount rate for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. GHG damage reduction benefits values include benefits associated CO_2, as well as other GHG pollutants, which have been converted to CO_{2eq}. Values may not sum to totals due to rounding.

Source: NERA/Trinity calculations as explained in text.

Table ES-4. Net Benefits Relative to Augural Standards Baseline, 7% Discount Rate (Billions of 2016$)

	Scenario 8	Scenario 5	Scenario 1
Social Costs			
Technology Costs	-51.8	-85.4	-128.5
Congestion Costs	-3.9	-6.5	-10.9
Noise Costs	-0.1	-0.1	-0.2
Fatal Crash Costs	-0.9	-1.1	-1.0
Non-Fatal Crash Costs	-1.2	-1.4	-1.3
Total Social Costs	**-57.8**	**-94.5**	**-141.8**
Social Benefits			
Valuation of Fuel Economy Benefits	-19.1	-33.3	-59.5
Fuel Tax Revenue Benefits	2.6	4.4	8.0
Petroleum Market Externality Benefits	-0.8	-1.3	-2.3
GHG Damage Reduction Benefits	-0.2	-0.3	-0.7
NO_x Damage Reduction Benefits	0.0	0.1	0.0
VOC Damage Reduction Benefits	0.0	0.0	-0.1
$PM_{2.5}$ Damage Reduction Benefits	-0.2	-0.5	-1.0
SO_2 Damage Reduction Benefits	-1.2	-2.0	-3.6
Total Social Benefits	**-18.9**	**-32.9**	**-59.3**
Net Total Benefits	**38.9**	**61.6**	**82.6**

Note: Present values calculated as of January 1, 2017 using a 7 percent discount rate for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. GHG damage reduction benefits values include benefits associated CO_2, as well as other GHG pollutants, which have been converted to CO_{2eq}. Values may not sum to totals due to rounding.

Source: NERA/Trinity calculations as explained in text.

These results using both a 3 percent and 7 percent discount rate indicate that all three alternatives would lead to net benefits, i.e., the reductions in social costs would be greater than the reductions in social benefits if any of the three CAFE alternatives replaced the Augural standards.

I. Introduction

This report evaluates alternative corporate average fuel economy (CAFE) standards for passenger cars and light trucks (collectively, "vehicles") for model year (MY) 2021 to MY 2026.[4] The evaluations are based upon a suite of models that include those developed by government agencies as well as those developed by NERA Economic Consulting (NERA) and Trinity Consultants (Trinity).

Our evaluations include estimates of the market effects and other regulatory impacts (e.g., changes in new vehicle sales and emissions) of alternative CAFE standards as well as estimates of the societal costs and societal benefits of these standards. These estimates result in estimates of the net benefits (i.e., social benefits minus social costs) of alternatives.

A. Regulatory Background

In August 2018, NHTSA and EPA jointly released a notice of proposed rulemaking (NPRM)—the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks (SAFE Vehicles Rule)—along with supporting materials that included a preliminary regulatory impact analysis (PRIA). In the PRIA, NHTSA and EPA evaluated eight alternatives, all relative to the current set of standards (which is the "no action" alternative). This no action alternative assumes that the MY 2021 standards remain in place, that the MY 2022-2025 Augural CAFE standards are finalized and that MY 2026 standards are set at MY 2025 levels.[5] For ease of exposition, we refer to this baseline scenario as the "augural standards baseline." Note that our analyses evaluate alternative CAFE standards relative to this augural standards baseline. Table 1 summarizes the eight alternative standards noted in the NRPM. The Baseline/No-Action alternative is included at the end of the table, reflecting the fact that it is the most stringent of the alternatives evaluated.

[4] NHTSA and EPA also evaluated standards for carbon dioxide (CO_2) emissions for the same model years. We estimate effects of the alternative CAFE standards and do not develop separate estimates for alternative CO_2 standards. Since the two sets of standards are harmonized, however, our comparative results for the alternative CAFE standards should apply to the equivalent CO_2 standards (although the specific estimates would differ).

[5] See e.g., Table I-4 of the NHTSA/EPA NPRM (2018a).

Table 1. CAFE Alternatives Evaluated in the NHTSA/EPA NPRM

Alternative	Change in Stringency	A/C efficiency and off-cycle provisions.
1	Existing standards through MY 2020, then 0%/year increases for both passenger cars and light trucks, for MYs 2021-2026	No change
2	Existing standards through MY 2020, then 0.5%/year increases for both passenger cars and light trucks, for MYs 2021-2026	No change
3	Existing standards through MY 2020, then 0.5%/year increases for both passenger cars and light trucks, for MYs 2021-2026	Phase out these adjustments over MYs 2022-2026
4	Existing standards through MY 2020, then 1%/year increases for passenger cars and 2%/year increases for light trucks, for MYs 2021-2026	No change
5	Existing standards through MY 2021, then 1%/year increases for passenger cars and 2%/year increases for light trucks, for MYs 2022-2026	No change
6	Existing standards through MY 2020, then 2%/year increases for passenger cars and 3%/year increases for light trucks, for MYs 2021-2026	No change
7	Existing standards through MY 2020, then 2%/year increases for passenger cars and 3%/year increases for light trucks, for MYs 2021-2026	Phase out these adjustments over MYs 2022-2026
8	Existing standards through MY 2021, then 2%/year increases for passenger cars and 3%/year increases for light trucks, for MYs 2022-2026	No change
Baseline/ No-Action	MY 2021 standards remain in place; MYs 2022-2025 augural CAFE standards are finalized; MY 2026 standards are set at MY 2025 level	No change

Source: NHTSA/EPA (2018a).

B. Objective of this Study

The principal objective of this study is to estimate the potential impacts of alternative CAFE standards using a combination of models including those used by NHTSA in the PRIA as well as those developed by NERA and Trinity for this study. The NERA models include a model of the new vehicle market that provides estimates of the values that new vehicle purchasers place on changes in fuel economy as well as a model of the relationship between changes in new vehicle prices and changes in the scrappage of different vintages of existing vehicles. We rely upon information developed by NHTSA for estimates of the identification, cost and effectiveness of alternative technologies to improve fuel economy for individual manufacturers and motor vehicle models—information that is contained in the version of the CAFE Model that was released by NHTSA when the NPRM was released. (This model was previously identified as the Volpe Model.)

We develop estimates for three of the eight alternatives that were included in the PRIA, as shown in Table 2. The three alternatives correspond to Alternative 1, Alternative 5, and Alternative 8 and thus span the range of stringency included in the PRIA. As in the PRIA, we evaluate each of the three alternatives relative to the "no action" augural standards, which are more stringent than any of the three alternatives. Note that throughout this report we order the alternatives in terms of decreasing stringency, i.e., Alternative 8, 5 and 1, all of which are less stringent than the baseline augural standards.

Table 2. CAFE Alternatives Evaluated in This Study

Alternative	Change in stringency
Baseline/ No-Action ("Augural")	MY 2021 standards remain in place; MYs 2022-2025 augural CAFE standards are finalized; MY 2026 standards are set at MY 2025 levels
8	Existing standards through MY 2021, then 2%/year increases for passenger cars and 3%/year increases for light trucks, for MYs 2022-2026
5	Existing standards through MY 2021, then 1%/year increases for passenger cars and 2%/year increases for light trucks, for MYs 2022-2026
1	Existing standards through MY 2020, then 0%/year increases for both passenger cars and light trucks, for MYs 2021-2026

Note: There are no changes in A/C Efficiency or off-cycle provisions between these alternatives.

C. Outline of the Report

The remainder of this report is organized as follows. Chapter II provides information on our methodology for evaluating the effects of the alternative CAFE standards, including information on the various models used in the analyses. Chapter III provides estimates of the market and regulatory impacts of the three alternative CAFE standards, including impacts on new vehicle sales, fleet population effects, VMT, gasoline consumption and air emissions. Chapter IV provides estimates of changes in social costs, including the costs to modify new motor vehicles as well as various costs related to changes in VMT (congestion, noise and crash costs). Chapter V provides estimates of changes in social benefits, including the value of fuel economy changes, VMT changes, refueling time changes, changes in government fuel tax revenues as well as market externality effects of changes in fuel use and changes in emissions benefits for greenhouse gas (GHG) emissions and criteria pollutant emissions. Chapter VI provides estimates of the net benefits (i.e., benefits minus costs) of the three alternatives. Various appendices provide information on the models and details regarding the analyses that underlie the estimates.

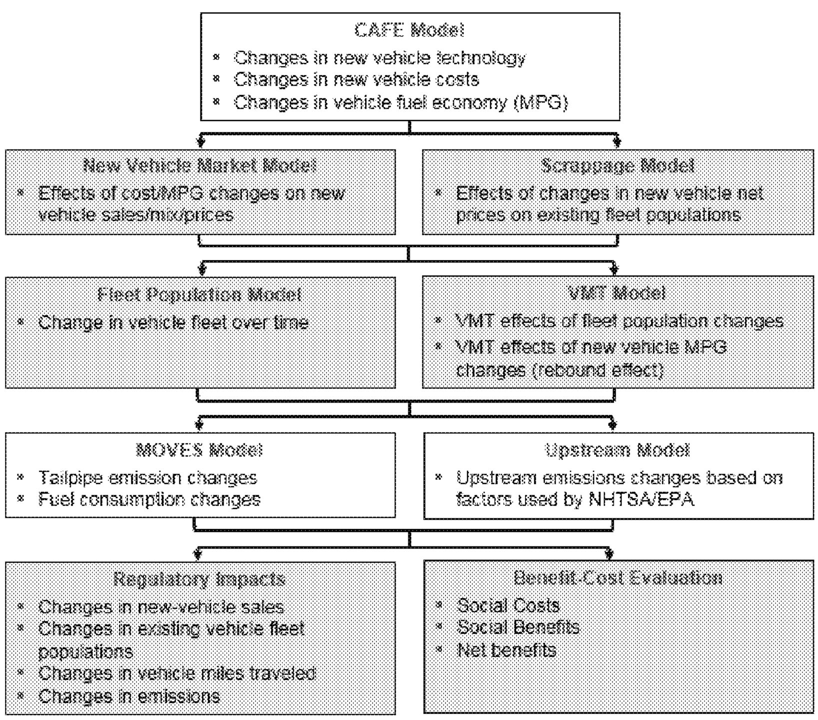
II. Modeling Methodology

This chapter provides information on the methodologies used to estimate the effects of the alternative CAFE standards on the vehicle fleet, on VMT, on fuel consumption, and on emissions. As noted, appendices to this report provide details on the individual models and the data that was used in their estimation and implementation.

A. Overview of Modeling Structure

The modeling framework allows us to estimate the impacts of alternative CAFE standards on the motor vehicle fleet—including changes in new vehicle sales and changes in the scrappage of existing vehicles—as well as on VMT over the analysis period, which is from 2017 to 2050. Results are developed for vehicles and VMT for model years (MY) through MY 2029. Figure 1 provides an overview of the framework, showing the models used and their interactions, with models in white those developed by government agencies and models in blue developed by NERA and Trinity. Details regarding these models are provided in appendices.

Figure 1. Overview of Model Structure



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B. CAFE Model

The 2018 CAFE Model[6] developed by the U.S. Department of Transportation (DOT)—subsequently referred to in this report as the CAFE Model—was used as the first element of the modeling. Trinity used the CAFE Model to estimate changes in new vehicle technology penetrations, costs and fuel economy/CO_2 emissions by model year for the U.S. light-duty vehicle fleet under the alternative CAFE standards. Table 2 above summarizes the three alternative sets of CAFE standards that were evaluated, all relative to the augural standards that constitute the baseline.

The CAFE Model input files and run configuration options were generally set to those used by NHTSA to support the "Unconstrained" analysis[7] referred to in the Draft Environmental Impact Analysis (DEIS). Trinity did not modify any of the basic information on the costs and effectiveness of technology options to improve vehicle fuel economy that are included in the CAFE Model. Appendix A contains information on the CAFE Model and the implementation in this analysis.

C. New Vehicle Market Model

NERA developed the New Vehicle Market Model, a model of the U.S. market for new vehicles that is used to analyze the effects of alternative CAFE standards on new vehicle sales and prices. The New Vehicle Market Model has the structure of a nested logit model, a formulation that has been used extensively by economists to characterize motor vehicle markets.[8] The model is calibrated and estimated using data on transaction prices and other vehicle characteristics for almost 300 individual models for vehicles in model year (MY) 2013 to MY 2017. The New Vehicle Market Model allows us to estimate the value that new vehicle purchasers place on fuel economy improvements (via changes in operating costs) based upon observed market behavior. The model also allows us to calculate net price increases for new vehicles—i.e., price increases net of the value that new vehicle purchasers place on fuel economy changes—due to the alternative standards.

The New Vehicle Market Model is an improvement over estimates of the value of fuel economy and new vehicle choice based upon assumed payback periods and other *ad hoc* approaches.[9]

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[6] The version of the CAFE Model used for this analysis was the "2018 NRPM" version released by the National Traffic Safety Administration in August, 2018 in support of the proposed NPRM: https://www.nhtsa.gov/corporate-average-fuel-economy/compliance-and-effects-modeling-system.

[7] As described in Section 2.3.2 of the DEIS, NHTSA's CAFE Model results presented in the NPRM and PRIA differ slightly from those presented in the DEIS. The Energy Policy and Conservation ACT (EPCA) and Energy Independence and Security Act (EISA) require that the Secretary determine the maximum feasible levels of CAFE standards in a manner that sets aside the potential use of CAFE credits or application of alternative fuels toward compliance with new standards. NEPA, however, does not impose such constraints on analysis; instead, its purpose is to ensure that "public officials make decisions with an understanding of environmental consequences." The DEIS therefore presents results of an "unconstrained" analysis that considers manufacturers' potential use of CAFE credits and application of alternative fuels in order to disclose and allow consideration of the real-world environmental consequences of the Proposed Action and alternatives.

[8] See, e.g., Bunch et al. (2011); Harrison et al. (2008); Greene et al. (2005); Train (1986); and Ben Akiva and Lerman (1985).

[9] See e.g., Greene (2012), pp. 18-19 for a discussion of various methodologies used to estimate consumer valuations of fuel economy.

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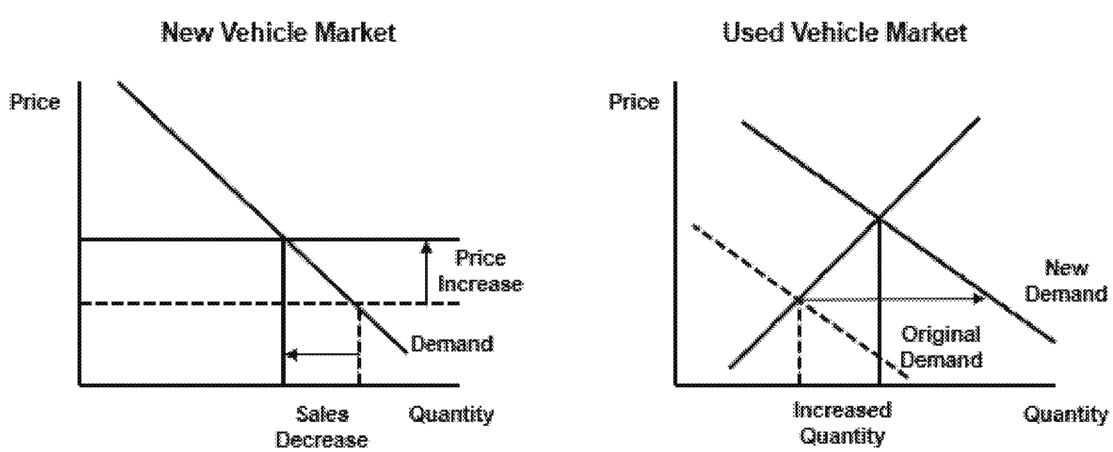
Using results from the New Vehicle Market Model and estimates from the CAFE Model of changes in costs and fuel economies for various models due to the alternative standards, we develop estimates of the changes in new vehicle sales due to the alternative standards. Appendix B provides a detailed description of the data and statistical methodologies used to develop the New Vehicle Market Model as well as the model results.

D. Scrappage Model

Previous research has established that new vehicle prices affect used vehicle scrappage rates.[10] Using a conceptual framework developed by previous researchers, we have developed an updated statistical model relating used-vehicle scrappage rates to new vehicle prices. The Scrappage Model includes statistically-estimated relationships between scrappage rates for vehicles of different model year vintages at each age during their lifetimes to new vehicle prices and other relevant factors.

Figure 2 provides a simple illustration of the effects of changes in the new vehicle market on the used vehicle market. The left-hand figure illustrates the case for the new vehicle market if CAFE standards lead to a net increase in the cost of new vehicles (i.e., costs greater than value of fuel economy gains), leading to an increase in price and a decrease in new vehicle sales. Because new vehicles are more expensive, the demand for used vehicles (a substitute good) increases, an effect illustrated in the right-hand figure. The increased demand for used vehicles leads to increases in their prices as well as increases in the quantity of used vehicles in the fleet. The change in quantity occurs from changes in scrappage rates; if used vehicles command higher prices, this provides a market signal to keep existing vehicles longer and thus scrappage rates decline. Note that this simple diagram abstracts from many specifics of the potential impacts on the existing fleet (e.g., scrappage effects differ by existing vehicle age). Appendix C provides a description of the Scrappage Model, including the data we use and the statistical estimates of the effects of changes in the new vehicle price on scrappage rates, accounting for other determinants of scrappage rates.

Figure 2. Effects of Changes in New Vehicles Prices on Prices/Quantities of Used Vehicles



[10] See, e.g., Gruenspecht (1983), as referenced in Appendix C.

These changes in vehicle scrappage due to CAFE standards are important because many of the effects of CAFE standards depend upon effects on the vehicle fleet. For example, criteria pollutants are affected by existing vehicle scrappage rates in two ways: (a) vehicles sold in the past were subject to less stringent standards; and (b) as vehicles age, their emission rates increase, whatever the emission rates were when the vehicles were new. For both reasons, additional older vehicles on the road will mean increased emissions. In addition, to the extent that older vehicles are less fuel efficient than new ones, having more older vehicles on the road would tend to reduce average fuel economy and thus also raise GHG emissions. Of course, the opposite effects would occur if there are fewer older vehicles on the road; everything else equal, fewer older vehicles would mean lower emissions of criteria emissions and GHG emissions.

E. Fleet Population Model

The Fleet Population Model combines the results of the New Vehicle Market Model and the Scrappage Model to project changes in vehicle fleet populations over time. The empirical results from the Scrappage Model are used in combination with the new vehicle sales effects from the New Vehicle Market Model to estimate the net effects of the alternative standards on the U.S. vehicle fleet over time. The Fleet Population Model keeps track of vehicles in model years up to MY 2029 over the analysis period from 2017 to 2050.

The baseline forecast of the relevant U.S. vehicle fleet population is based upon the vehicle populations in EPA's MOVES vehicle emission inventory model (see below). Fleet population effects due to the CAFE alternatives are measured relative to this baseline vehicle fleet population for MY 2029 and earlier vehicles. Appendix D provides more detailed information on the Fleet Population Model.

F. Vehicle Miles Traveled (VMT) Model

Many of the effects of the alternative CAFE standards depend upon impacts on VMT, including changes in safety, congestion and vehicle emissions. The results of the Fleet Population Model provide one important component of the VMT model to the extent that total fleet VMT could be influenced by the size and/or age-distribution of the fleet. Because older vehicles tend to be driven less than newer vehicles, changes in the age composition of the vehicle fleet would lead to changes in VMT. Similarly, if CAFE standards affect the size of the fleet through sales and scrappage effects that do not exactly offset, then total VMT could be affected. In our modeling, both sources of changes to fleet VMT are relatively small compared to the key component of the VMT model: changes in fuel economy for vehicles subject to the CAFE alternatives lead to changes in the cost of driving, which leads to an additional effect of the alternatives on VMT.

Improvements in fuel economy, as reflected in higher MPG, decrease the cost of driving and thus via a demand effect will lead to greater driving (VMT). This effect applies to all policies that affect energy efficiency and thus lead to a decrease in the price of energy and an increase in energy use; this effect is referred to as a "rebound effect" because the effect offsets in part the direct effect that leads to less energy use.

The rebound effect is defined as the elasticity of VMT with respect to fuel efficiency improvements, i.e., the percentage change in VMT associated with a one-percent change in fuel efficiency. (Reported elasticity estimates typically are multiplied by 100 so the rebound effect is expressed as a percentage, e.g., an elasticity of 0.2 is translated into a rebound effect of 20 percent, meaning that the percent increase in VMT is 20 percent of the percentage improvement in fuel efficiency.) Empirical estimates of the rebound effect are often based on estimated changes in VMT with respect to changes in fuel cost per mile or fuel prices.

The VMT Model starts with baseline VMT estimates by calendar year (from 2017 to 2050) based upon information on VMT by model year provided in the MOVES model. As noted above, our analyses include information on vehicles in model years up to MY 2029 and thus we do not include information from MOVES for vehicles in model years after 2029. We model the effects of the CAFE alternatives on VMT by including the two effects noted above: (a) changes due to modifications in the vehicle fleet as estimated for new vehicles in each year by the New Vehicle Market Model and for the existing fleet by the Scrappage Model; and (b) changes due to the rebound effect, which changes VMT for vehicles in the model years with differences in fuel economy due to the CAFE alternatives.

Appendix E provides information on the VMT Model including our determination of an appropriate rebound effect based on an assessment of the substantial empirical literature. We conclude that 20 percent is the most likely estimate of the rebound effect based upon the available studies.

G. Emissions Modeling

1. MOVES Model

MOVES (for Motor Vehicle Emissions Simulator) is the vehicle emissions model developed by the U.S. EPA to estimate criteria pollutant and CO_2-equivalent emissions from U.S. on-road motor vehicles over nationwide, regional and localized scales under a wide range of fleet characteristics, ambient conditions, and operating conditions. MOVES is based on exhaustive vehicle emission testing measurements collected under both laboratory and in-use conditions and is designed to estimate on-road vehicle fleet emissions and changes over time from on-going changes to federal new vehicle emission standards as well as local control programs.

The latest version of MOVES, MOVES2014b (released in August 2018) was used by Trinity to estimate the change in CO_2-equivalent and criteria pollutant emissions for the U.S. vehicle fleet due to the alternative CAFE standards. These vehicle emissions estimates used estimates of future light-duty vehicle fleets developed by NERA, which as summarized above accounted for the 20 percent rebound effect as well as new vehicle purchase and scrappage effects.

Unlike the CAFE Model, MOVES does not evaluate CO_2-equivalent and criteria emissions impacts of alternative CAFE standards. The values in MOVES reflect the augural standards. Trinity adjusted MOVES CO_2 and criteria emissions to reflect the fuel economy/CO_2 emission rate differences between the augural standards and the three CAFE alternatives evaluated in this study. Appendix F provides further details on how MOVES was used to estimate U.S. light-duty vehicle fleet emission changes and fuel consumption changes.

2. Upstream Model

Upstream emissions refer to the emissions associated with fuel production including refining, distribution, and delivery. The Upstream Model consists of estimates of upstream emissions factors used by NHTSA/EPA in the PRIA that are included in the CAFE Model parameters file. The PRIA notes that the upstream emission factors relied on by the agencies for each fuel type are based on the energy content and emission rates per unit of fuel energy refined and distributed, as developed using the GREET Model developed by Argonne National Laboratories.

We convert these values (which are in grams per million BTUs) to grams per gallon based on the energy density assumptions for each relevant fuel type included in the CAFE Model parameters file. We then apply these factors to the changes in fuel consumption that we estimate based on our fleet population and VMT modeling. Appendix G provides further details on how we applied the NHTSA/EPA PRIA upstream emissions factors to develop estimates of upstream emissions for the alterative standards.

III. Motor Vehicle Market Impacts of Alternative CAFE Standards

This chapter summarizes the results of our analyses of the effects of alternative CAFE standards on motor vehicle markets and related impacts. The results are grouped into five categories:

1. New vehicle sales effects;
2. Existing vehicle scrappage and fleet population effects;
3. Vehicle miles traveled effects;
4. Gasoline and petroleum effects; and
5. Emissions effects.

The results reflect changes due to the three alternative CAFE standards relative to the baseline or no-action (augural) standards. As a result, positive values indicate that the quantity (e.g., new vehicle sales) is greater under the three alternatives than under the augural standards, whereas negative quantities indicate that the quantity (e.g., VMT) is smaller under the three alternatives than under the augural standards.

A. Impacts on New Vehicle Sales

Table 3 shows estimates of total new vehicle sales for MY 2021 to MY 2029 for the three alternatives as well as the augural standards (baseline). Table 4 shows estimates of the *differences* between each of the alternative standards and the augural standards baseline. Table 5 provides the differences in percentage terms. These results show that all three alternative standards would lead to increases in vehicle sales, which reflects estimates that all three standards would lead to decreases in the net price of new vehicles (i.e., the decrease in price is greater than the decrease in the value that new vehicle purchases place on the reduced fuel economy). The changes in costs and fuel economy for new vehicles are based upon the CAFE Model results CAFE Model; the valuations of changes in fuel economy are based upon results from the New Vehicle Market Model.

Table 3. New Vehicle Sales (thousands), MY 2021-2029

Model Year	Augural standards	Scenario 8	Scenario 5	Scenario 1
2021	17,953	18,001	18,027	18,060
2022	17,990	18,044	18,077	18,107
2023	18,039	18,099	18,135	18,164
2024	18,122	18,186	18,222	18,252
2025	18,479	18,551	18,590	18,622
2026	18,804	18,872	18,917	18,954
2027	19,058	19,121	19,174	19,210
2028	19,243	19,306	19,357	19,395
2029	19,345	19,404	19,455	19,490

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

Table 4. Differences in New Vehicle Sales (thousands) Compared to Augural Standards Baseline, MY 2021-2029

Model Year	Augural standards	Scenario 8	Scenario 5	Scenario 1
2021	--	48	74	107
2022	--	55	87	117
2023	--	60	96	125
2024	--	64	100	131
2025	--	73	111	143
2026	--	68	113	150
2027	--	63	116	153
2028	--	63	114	151
2029	--	59	109	145

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

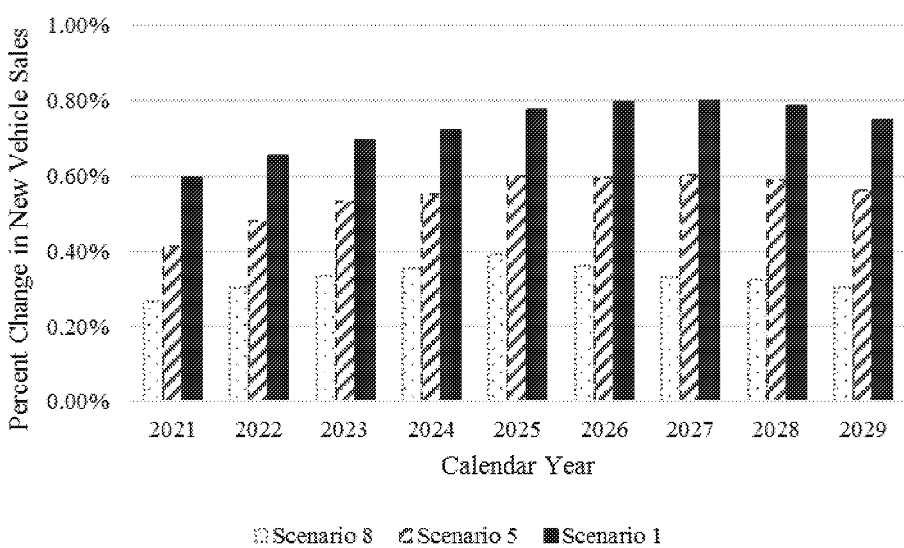
Table 5. Differences in New Vehicle Sales (% Change) Compared to Augural Standards Baseline, MY 2021-2029

	Augural standards	Scenario 8	Scenario 5	Scenario 1
2021	--	0.27%	0.41%	0.60%
2022	--	0.30%	0.48%	0.65%
2023	--	0.33%	0.53%	0.69%
2024	--	0.35%	0.55%	0.72%
2025	--	0.39%	0.60%	0.77%
2026	--	0.36%	0.60%	0.80%
2027	--	0.33%	0.61%	0.80%
2028	--	0.33%	0.59%	0.79%
2029	--	0.31%	0.56%	0.75%

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

The estimated changes in new vehicle sales vary among the three alternative CAFE standards as well as across model years. For MY 2025, for example, the estimated increase in new vehicle sales ranges from 73,000 vehicles for Alternative 8 to 143,000 vehicles for Alternative 1. Figure 3 shows these estimates as percentage changes relative to new vehicle sales under the augural standards. Over all nine model years, the average percentage increase in motor vehicle sales is 0.33% for Alternative 8, 0.55% for Alternative 5, and 0.73% for Alternative 1.

Figure 3. Percentage Differences in New Vehicle Sales Compared to Augural Standards Baseline, MY 2021-2029



Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

B. Impacts on Existing Vehicle Scrappage and Fleet Populations

Decreases in net new vehicle prices due to the alternative standards would lead to changes in the scrappage rates of older vehicles. Specifically, the lower net new car prices and increased numbers of new vehicles due to the less stringent CAFE standards would lead to reductions in the numbers of used vehicles on the road; these reductions would be accomplished by increases in the scrappage rates for existing vehicles. In any calendar year, the combination of the increase in new vehicle sales and the decrease in existing vehicles (through increased scrappage) would combine to change the overall vehicle fleet. The combined effect of more newer vehicles and fewer existing vehicles would lead to a gradual reduction in the average age of the vehicle fleet.

To provide an example of the estimated effects of the alternative CAFE standards on the motor vehicle fleet, Table 6 shows the numbers of vehicles by model year in 2030 under the three alternatives as well as the augural standards (baseline). The table shows the number of vehicles by model year (starting in MY 2001) that are estimated to make up the motor vehicle fleet in 2030.

Table 6. Number of Vehicles (thousands) by Model Year in Calendar Year 2030

Model Year	Augural Standards	Scenario 8	Scenario 5	Scenario 1
2001	368	357	351	347
2002	470	457	449	443
2003	561	545	537	530
2004	692	673	663	654
2005	834	812	800	790
2006	965	941	927	916
2007	1,190	1,162	1,146	1,133
2008	1,348	1,319	1,301	1,288
2009	1,106	1,083	1,070	1,060
2010	1,663	1,632	1,613	1,600
2011	2,066	2,031	2,009	1,994
2012	3,940	3,881	3,845	3,819
2013	5,039	4,973	4,933	4,904
2014	6,459	6,388	6,343	6,312
2015	8,034	7,961	7,915	7,883
2016	9,823	9,752	9,707	9,676
2017	11,375	11,312	11,272	11,245
2018	12,405	12,355	12,324	12,307
2019	13,188	13,152	13,128	13,121
2020	13,980	13,962	13,947	13,946
2021	14,766	14,772	14,768	14,777
2022	15,499	15,521	15,529	15,542
2023	16,153	16,190	16,209	16,225
2024	16,741	16,789	16,814	16,835
2025	17,497	17,559	17,590	17,616
2026	18,137	18,200	18,241	18,275
2027	18,633	18,695	18,746	18,782
2028	18,959	19,022	19,072	19,108
2029	19,203	19,262	19,312	19,347

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

Table 7 and Table 8 show the *differences* in the number of motor vehicles by model year relative to the augural standards baseline levels, both in absolute and percentage terms. In 2030, the number of vehicles on the road is greater than under the augural standards for the nine newest model years, while the number is smaller for the earlier model years. Note that the scrappage effect operates on model years that have larger new vehicle sales under the less-stringent standards. For MY 2021, for example, Table 4 shows an estimated 107,000 additional new vehicle sales under Alternative 1 relative to the augural standards; by 2030, however, accelerated scrappage results in only 11,000 more MY 2021 vehicles still on the road if Alternative 1 replaced the augural standards.

Table 7. Differences in Number of Vehicles (thousands) Compared to Augural Standards Baseline by Model Year in Calendar Year 2030

Model Year	Augural Standards	Scenario 8	Scenario 5	Scenario 1
2001	--	-10	-16	-21
2002	--	-13	-21	-26
2003	--	-15	-24	-31
2004	--	-18	-29	-37
2005	--	-22	-34	-43
2006	--	-24	-38	-48
2007	--	-28	-44	-56
2008	--	-30	-47	-60
2009	--	-23	-36	-46
2010	--	-31	-50	-63
2011	--	-35	-56	-72
2012	--	-59	-95	-121
2013	--	-65	-106	-135
2014	--	-71	-115	-147
2015	--	-73	-119	-151
2016	--	-72	-116	-148
2017	--	-63	-103	-129
2018	--	-50	-81	-98
2019	--	-36	-59	-67
2020	--	-19	-34	-34
2021	--	5	1	11
2022	--	22	31	43
2023	--	37	55	71
2024	--	48	73	94
2025	--	62	93	119
2026	--	63	104	138
2027	--	62	114	149
2028	--	62	112	149
2029	--	59	108	144

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

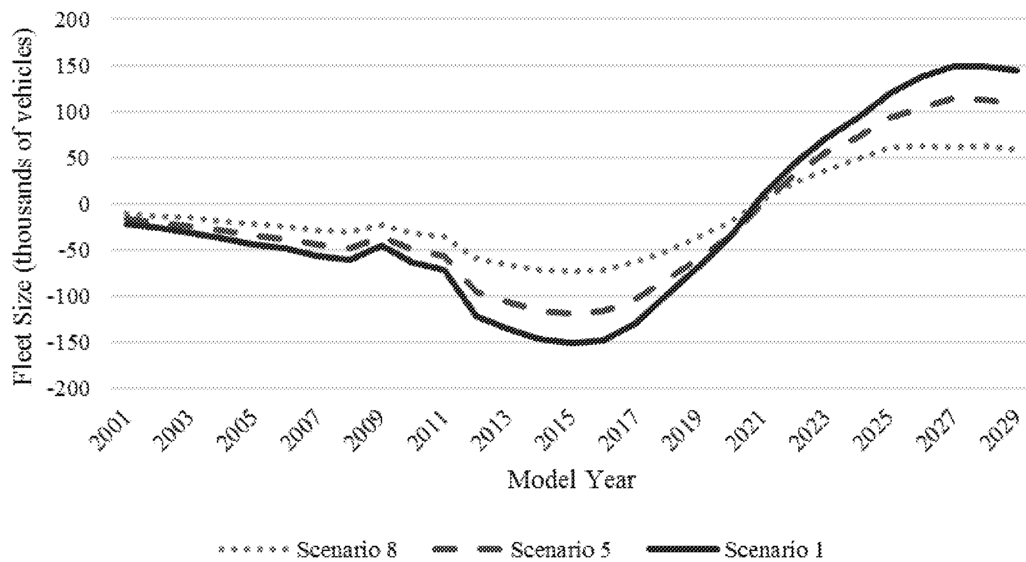
Table 8. Differences in Number of Vehicles (% Change) Compared to Augural Standards Baseline by Model Year in Calendar Year 2030

Model Year	Augural Standards	Scenario 8	Scenario 5	Scenario 1
2001	--	-2.85%	-4.46%	-5.74%
2002	--	-2.80%	-4.38%	-5.64%
2003	--	-2.74%	-4.29%	-5.52%
2004	--	-2.67%	-4.18%	-5.37%
2005	--	-2.58%	-4.06%	-5.20%
2006	--	-2.48%	-3.91%	-4.99%
2007	--	-2.36%	-3.73%	-4.75%
2008	--	-2.22%	-3.52%	-4.47%
2009	--	-2.05%	-3.27%	-4.14%
2010	--	-1.88%	-3.00%	-3.81%
2011	--	-1.70%	-2.73%	-3.47%
2012	--	-1.50%	-2.42%	-3.07%
2013	--	-1.30%	-2.10%	-2.68%
2014	--	-1.10%	-1.79%	-2.27%
2015	--	-0.91%	-1.48%	-1.88%
2016	--	-0.73%	-1.18%	-1.50%
2017	--	-0.55%	-0.90%	-1.13%
2018	--	-0.41%	-0.66%	-0.79%
2019	--	-0.27%	-0.45%	-0.51%
2020	--	-0.13%	-0.24%	-0.25%
2021	--	0.04%	0.01%	0.07%
2022	--	0.14%	0.20%	0.28%
2023	--	0.23%	0.34%	0.44%
2024	--	0.29%	0.43%	0.56%
2025	--	0.35%	0.53%	0.68%
2026	--	0.35%	0.57%	0.76%
2027	--	0.33%	0.61%	0.80%
2028	--	0.33%	0.59%	0.79%
2029	--	0.31%	0.56%	0.75%

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

Figure 4 illustrates the changes in 2030, showing differences in number of vehicles by model year compared to the augural standards baseline. The alternative standards have the effect of making the age distribution "newer" due to two effects: (a) more new vehicles are in service due to increases in new vehicle sales; and (b) fewer existing vehicles are in service through the effect of the higher new vehicle prices on increasing scrappage rates for used vehicles.

Figure 4. Differences in Fleet Effects Compared to Augural Standards Baseline by Model Year, for Calendar Year 2030 (all vehicles)



C. Impacts on Vehicle Miles Traveled (VMT)

The CAFE alternatives can affect VMT in three major ways. First, new sales and scrappage effects combine to affect the age composition of the fleet, with newer vehicles generally driving more miles in a year than older vehicles. Second, the balance of sales and scrappage effects can affect the size of the fleet, which would affect the level of VMT. Finally, and most significantly, CAFE alternatives affect VMT for vehicles subject to the alternative standards through the "rebound effect," i.e., the effect of changes in the per-mile cost of driving (via changes in fuel economy) on the number of miles traveled.

Table 9 provides estimates of total VMT in each CAFE alternative or every five years from 2020 to 2050. We emphasize that these values only include miles driven for motor vehicles in model years up to MY 2029. Thus, the total VMT decreases in later years as we focus on an increasingly small subset of the total fleet.

Table 9. VMT (billions) for Select Calendar Years

Calendar Year	Augural standards	Scenario 8	Scenario 5	Scenario 1
2020	2,798.1	2,797.0	2,796.4	2,794.8
2025	2,923.1	2,915.4	2,911.0	2,903.5
2030	2,807.6	2,795.4	2,786.7	2,773.0
2035	1,687.9	1,680.4	1,674.8	1,665.4
2040	786.7	783.7	781.3	776.7
2045	256.0	254.9	254.1	252.5
2050	70.6	70.4	70.1	69.6

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

Table 10 and Table 11 show the effects of the three alternatives on the VMT over time by calculating the differences in the VMT relative to the augural standards baseline levels, both in absolute and percentage terms. VMT is highest under the augural standards and lowest under Alternative 1 in all calendar years. In terms of percentage increases, in 2030, for example, the 34.5 billion miles reduction in VMT for Alternative 1 would represent about a 1.23% decrease in VMT relative to the augural standards.

Table 10. Differences in VMT (billions) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Augural Standards	Scenario 8	Scenario 5	Scenario 1
2020	--	-1.1	-1.7	-3.3
2025	--	-7.7	-12.1	-19.5
2030	--	-12.1	-20.8	-34.5
2035	--	-7.4	-13.1	-22.4
2040	--	-3.0	-5.4	-9.9
2045	--	-1.1	-1.9	-3.5
2050	--	-0.2	-0.5	-1.0

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

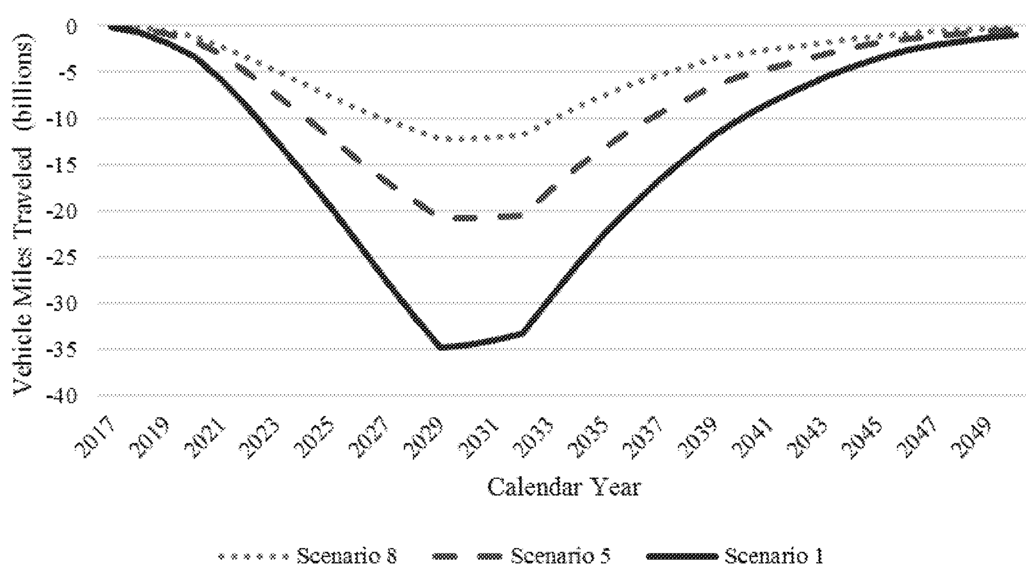
Table 11. Differences in VMT (% Change) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Augural Standards	Scenario 8	Scenario 5	Scenario 1
2020	--	-0.04%	-0.06%	-0.12%
2025	--	-0.26%	-0.41%	-0.67%
2030	--	-0.43%	-0.74%	-1.23%
2035	--	-0.44%	-0.78%	-1.33%
2040	--	-0.38%	-0.69%	-1.26%
2045	--	-0.42%	-0.72%	-1.35%
2050	--	-0.31%	-0.64%	-1.38%

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

Figure 5 provides a graphical illustration of the changes in U.S. VMT under the alternative CAFE standards, relative to VMT under the Baseline scenario in each calendar year. This graph shows that the less stringent CAFE standards (relative to the augural standards) are estimated to lead to decreases in VMT.

Figure 5. Change in Vehicles Miles of Travel (VMT) (Millions of Miles/Year)



Note: Values includes passenger cars and light trucks.
Source: NERA and Trinity calculations as explained in text.

D. Impacts on Fuel Consumption

The alternative CAFE standards would affect motor fuel consumption through various effects including: (a) effects on the fuel economy of the new vehicles subject to the standards as well as on the numbers of new vehicles sold; (b) effects on the numbers of existing vehicles on the road; and (c) through the rebound effect, changes in the VMT of the new vehicles whose fuel economy would be lower. As seen above, VMT is lower for each of the less-stringent CAFE alternatives compared to the augural standards. The effects on fuel consumption, however, will also depend on the effects on the fuel economy of the vehicles traveling those miles.

Table 12 shows estimates of the motor fuel consumed (cumulative for gasoline, diesel, and E85) for the three CAFE alternatives and the augural standards in five-year intervals from 2020 to 2050. We emphasize again that these estimates only include fuel consumption for model years up to MY 2029, and thus the total fuel consumption decreases substantially over time as the estimates cover an increasingly small subset of the fleet.

Table 12. Gallons of Motor Fuel Consumption (billions) for Select Calendar Years

Calendar Year	Augural Standards	Scenario 8	Scenario 5	Scenario 1
2020	116.3	116.4	116.4	116.6
2025	104.1	104.7	105.2	106.1
2030	89.3	90.5	91.3	92.9
2035	51.3	52.2	52.8	53.9
2040	23.4	23.9	24.3	24.9
2045	7.8	8.0	8.1	8.3
2050	2.2	2.3	2.3	2.4

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

Table 13 and Table 14 shows the effects of the three alternatives on motor fuel consumption in select calendar years by calculating the differences in gallons of fuel consumed relative to the augural standards baseline levels, both in absolute and percentage terms. Fuel consumption is greatest under Alternative 1, reflecting the fact that Alternative 1 leads to the lowest fuel economy (i.e., lowest MPG).

Table 13. Increases in Motor Fuel Consumption (billions of gallons) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Augural Standards	Scenario 8	Scenario 5	Scenario 1
2020	--	0.1	0.1	0.4
2025	--	0.7	1.1	2.1
2030	--	1.2	2.0	3.6
2035	--	0.9	1.5	2.6
2040	--	0.5	0.8	1.4
2045	--	0.2	0.3	0.5
2050	--	0.0	0.1	0.2

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

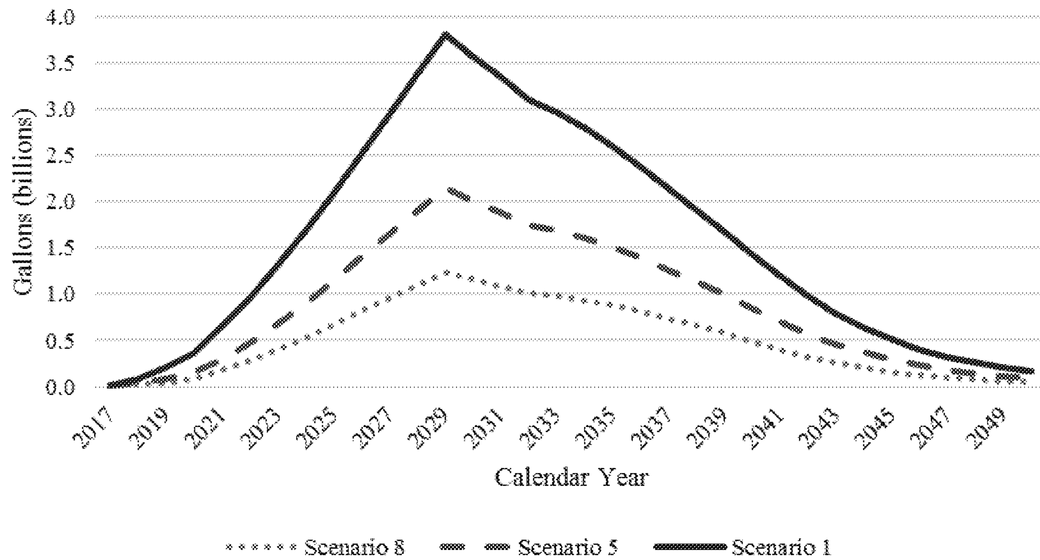
Table 14. Increases in Motor Fuel Consumption (% Change) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Augural standards	Scenario 8	Scenario 5	Scenario 1
2020	--	0.07%	0.13%	0.31%
2025	--	0.64%	1.09%	2.00%
2030	--	1.30%	2.25%	4.00%
2035	--	1.71%	2.94%	5.06%
2040	--	2.09%	3.61%	6.09%
2045	--	2.05%	3.73%	6.54%
2050	--	2.24%	4.15%	7.45%

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

Figure 6 provides a graphical illustration of the estimated increases in motor fuel consumption for the three alternative CAFE standards over time. Fuel consumption increases for all three alternatives relative to the levels under the augural standards, reflecting the lower average MPG of the fleet. In 2029, estimated light-duty vehicle fuel consumption is 98 billion gallons under the augural standards—thus the 3.8 billion-gallon increase under Scenario 1 represents a 3.9 percent change. Among all uses of motor gasoline and diesel, which are projected to total 166 billion gallons in Annual Energy Outlook 2018 (EIA AEO 2018), this would represent a 1.29 percent change.

Figure 6. Increases in Motor Fuel Consumption Compared to Augural Standards Baseline by Calendar Year



Note: Gallon values include gasoline, diesel, and E85 fuel consumption.

E. Impacts on Greenhouse Gas Emissions

The alternative CAFE standards affect two sources of greenhouse gas (GHG) emissions.

1. *Tailpipe emissions*. The alternative standards would impact tailpipe emissions through the changes in the age composition of the vehicle fleet (i.e., older vehicles are less fuel-efficient) and as well as through changes in VMT (i.e., increased VMT leads to greater emissions). We develop estimates of tailpipe emissions using the MOVES Model.

2. *Upstream emissions*. The alternative standards would impact upstream emissions through changes in demand for petroleum-based fuels. We develop estimates of the upstream emissions using the upstream emissions factors (emissions/gallon) used by NHTSA/EPA in the PRIA, which are based on the GREET Model developed by the Argonne National Laboratory. The upstream emissions factors represent the emissions associated with fuel production including refining, distribution, and delivery.

Table 15 provides estimates of GHG emissions for the each of the four CAFE scenarios, including the augural standards baseline. We report tailpipe and upstream emissions separately. Our estimates of GHG emissions are expressed as CO_2 equivalents and include CO_2, N_2O, and CH_4 emissions.

Table 15. GHG Emissions (millions of metric tons) for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	998.5	997.9	997.7	997.0
	Upstream	347.4	347.7	347.8	348.5
	Total	**1,345.9**	**1,345.6**	**1,345.5**	**1,345.5**
2025	Tailpipe	880.9	890.0	894.7	920.1
	Upstream	285.1	286.9	288.2	290.8
	Total	**1,166.0**	**1,176.9**	**1,182.9**	**1,210.9**
2030	Tailpipe	737.4	756.3	771.1	823.9
	Upstream	241.3	244.4	246.8	251.0
	Total	**978.7**	**1,000.7**	**1,017.8**	**1,074.8**
2035	Tailpipe	422.3	438.0	450.0	489.5
	Upstream	138.7	141.1	142.8	145.7
	Total	**561.0**	**579.1**	**592.8**	**635.3**
2040	Tailpipe	192.7	201.8	209.0	230.9
	Upstream	63.6	64.9	65.9	67.4
	Total	**256.2**	**266.7**	**274.9**	**298.4**
2045	Tailpipe	64.6	67.6	70.2	78.5
	Upstream	21.1	21.5	21.9	22.5
	Total	**85.7**	**89.1**	**92.1**	**101.0**
2050	Tailpipe	18.4	19.3	20.1	22.8
	Upstream	5.9	6.1	6.2	6.4
	Total	**24.4**	**25.3**	**26.2**	**29.2**

Note: Results include both passenger cars and light trucks. GHG emissions presented as CO_2 equivalents and include CO_2, N_2O, and CH_4 emissions.
Source: NERA/Trinity calculations as explained in text.

Table 16 and Table 17 provides estimates of the GHG emissions for each of the three alternative standards relative to the augural standards baseline, including the estimated differences and the differences expressed as a percentage of augural standards.

Table 16. Differences in GHG Emissions (millions of metric tons) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	-0.6	-0.8	-1.5
	Upstream	--	0.2	0.4	1.1
	Total	--	**-0.3**	**-0.4**	**-0.5**
2025	Tailpipe	--	9.0	13.8	39.2
	Upstream	--	1.8	3.1	5.7
	Total	--	**10.9**	**16.9**	**44.9**
2030	Tailpipe	--	18.9	33.7	86.5
	Upstream	--	3.1	5.4	9.7
	Total	--	**22.0**	**39.1**	**96.1**
2035	Tailpipe	--	15.6	27.7	67.2
	Upstream	--	2.4	4.1	7.0
	Total	--	**18.0**	**31.8**	**74.2**
2040	Tailpipe	--	9.1	16.4	38.3
	Upstream	--	1.3	2.3	3.9
	Total	--	**10.5**	**18.7**	**42.1**
2045	Tailpipe	--	2.9	5.6	13.9
	Upstream	--	0.4	0.8	1.4
	Total	--	**3.4**	**6.4**	**15.2**
2050	Tailpipe	--	0.8	1.6	4.4
	Upstream	--	0.1	0.2	0.4
	Total	--	**1.0**	**1.9**	**4.8**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

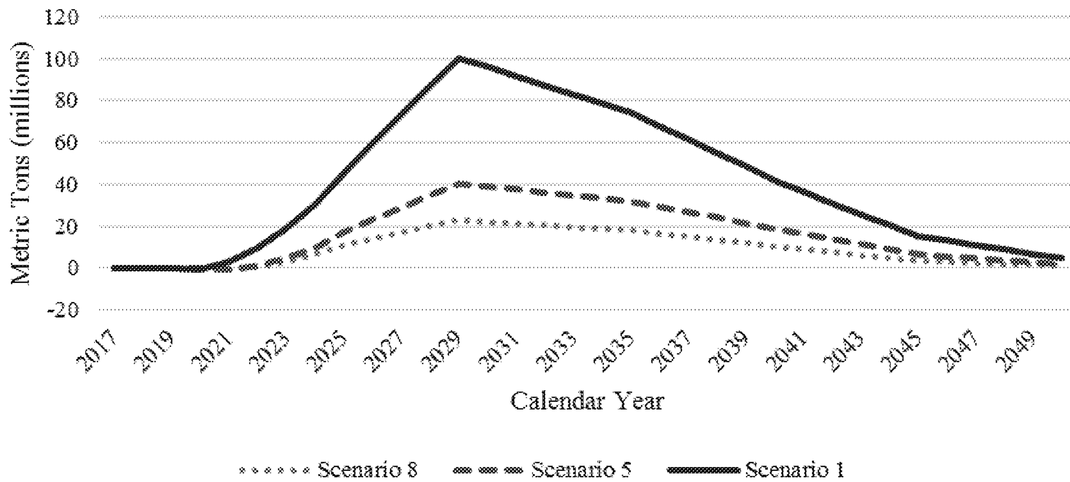
Table 17. Differences in GHG Emissions (% Change) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	-0.06%	-0.08%	-0.15%
	Upstream	--	0.07%	0.12%	0.31%
	Total	--	**-0.02%**	**-0.03%**	**-0.04%**
2025	Tailpipe	--	1.03%	1.56%	4.45%
	Upstream	--	0.64%	1.09%	2.00%
	Total	--	**0.93%**	**1.45%**	**3.85%**
2030	Tailpipe	--	2.56%	4.56%	11.72%
	Upstream	--	1.30%	2.25%	4.01%
	Total	--	**2.25%**	**3.99%**	**9.82%**
2035	Tailpipe	--	3.71%	6.56%	15.91%
	Upstream	--	1.72%	2.95%	5.07%
	Total	--	**3.21%**	**5.67%**	**13.23%**
2040	Tailpipe	--	4.74%	8.51%	19.86%
	Upstream	--	2.10%	3.62%	6.10%
	Total	--	**4.08%**	**7.29%**	**16.45%**
2045	Tailpipe	--	4.55%	8.64%	21.43%
	Upstream	--	2.05%	3.73%	6.55%
	Total	--	**3.94%**	**7.43%**	**17.77%**
2050	Tailpipe	--	4.48%	8.86%	23.81%
	Upstream	--	2.24%	4.15%	7.46%
	Total	--	**3.93%**	**7.71%**	**19.82%**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Figure 7 illustrates the estimated changes in GHG emissions (expressed as CO_2 equivalents) of the three alternative CAFE standards we evaluate over the analysis period. (As noted, the results are only for model years up to MY 2029.) The GHG emissions increase for all three alternatives, reflecting the increase in fuel consumption due to the less fuel-efficient fleets under the less-stringent CAFE standards. In 2029—the year with the greatest impact—the estimated total CO_{2eq} emissions for the light fleet are 1.08 billion metric tons; thus the 99.7 million metric ton increase under Scenario 1 represents a 9.3 percent change in light fleet emissions. The change in CO_{2eq} emissions in 2029 would represent a 2.0 percent change in U.S. economy wide emissions, based upon a projection of 5.1 billion metric tons in 2029 (EIA AEO 2018).

Figure 7. Differences in GHG Emissions (CO_{2eq}) relative to Augural Standards Baseline by Calendar Year



Note: GHG emissions presented as CO_2 equivalents and include CO_2, N_2O, and CH_4 emissions.

F. Impacts on Criteria Pollutant Emissions

The alternative CAFE standards would result in changes in criteria emissions, which include emissions for which air quality criteria have been set as well as precursor emissions, i.e., emissions that influence the level of criteria pollutants. The MOVES Model is used to estimate effects on tailpipe emissions. The tailpipe emissions from MOVES are supplemented by estimates of the effects of changes in upstream emissions based on upstream factors used by NHTSA/EPA for the PRIA developed from the GREET Model. We develop estimates for five criteria pollutants:

- Nitrogen oxides (NOx), both a criteria pollutant and a precursor for ambient ozone and particulate matter;
- Volatile organic compounds (VOC), a precursor pollutant for ambient ozone;
- Particulate matter ($PM_{2.5}$), a criteria pollutant;
- Sulfur dioxide (SO_2), a criteria pollutant and a precursor for $PM_{2.5}$; and
- Carbon monoxide, a criteria pollutant;

1. Impacts on NO_X Emissions

Table 18 provides our estimates of NO_X emissions for each of the alternative scenarios as well as for the augural standards baseline.

Table 18. NO_X Emissions (thousands of metric tons) for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	733.1	732.8	732.0	730.7
	Upstream	208.9	209.0	209.1	209.5
	Total	**942.0**	**941.9**	**941.2**	**940.2**
2025	Tailpipe	414.6	411.4	409.8	407.9
	Upstream	180.2	181.3	182.2	183.8
	Total	**594.8**	**592.8**	**591.9**	**591.7**
2030	Tailpipe	264.7	262.3	260.8	259.3
	Upstream	155.3	157.3	158.8	161.5
	Total	**420.0**	**419.6**	**419.6**	**420.8**
2035	Tailpipe	157.3	156.6	156.1	155.6
	Upstream	88.6	90.1	91.2	93.1
	Total	**245.9**	**246.7**	**247.3**	**248.7**
2040	Tailpipe	78.6	78.5	78.4	78.3
	Upstream	39.5	40.4	41.0	41.9
	Total	**118.1**	**118.8**	**119.4**	**120.3**
2045	Tailpipe	29.2	29.1	29.1	29.1
	Upstream	13.3	13.5	13.8	14.1
	Total	**42.4**	**42.7**	**42.9**	**43.3**
2050	Tailpipe	8.5	8.5	8.5	8.5
	Upstream	3.8	3.9	4.0	4.1
	Total	**12.3**	**12.4**	**12.5**	**12.6**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Table 19 and Table 20 provide our estimates of NO_X emissions for each of the alternative scenarios relative to the augural standards baseline, both in absolute and percentage terms.

Table 19. Differences in NO_X Emissions (thousands of metric tons) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	-0.3	-1.1	-2.4
	Upstream	--	0.1	0.3	0.7
	Total	--	**-0.1**	**-0.8**	**-1.7**
2025	Tailpipe	--	-3.2	-4.9	-6.7
	Upstream	--	1.2	2.0	3.6
	Total	--	**-2.0**	**-2.9**	**-3.1**
2030	Tailpipe	--	-2.4	-3.9	-5.4
	Upstream	--	2.0	3.5	6.2
	Total	--	**-0.4**	**-0.4**	**0.8**
2035	Tailpipe	--	-0.7	-1.2	-1.7
	Upstream	--	1.5	2.6	4.5
	Total	--	**0.8**	**1.4**	**2.8**
2040	Tailpipe	--	-0.1	-0.2	-0.2
	Upstream	--	0.8	1.4	2.4
	Total	--	**0.7**	**1.3**	**2.2**
2045	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	0.3	0.5	0.9
	Total	--	**0.2**	**0.5**	**0.8**
2050	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	0.1	0.2	0.3
	Total	--	**0.1**	**0.2**	**0.3**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

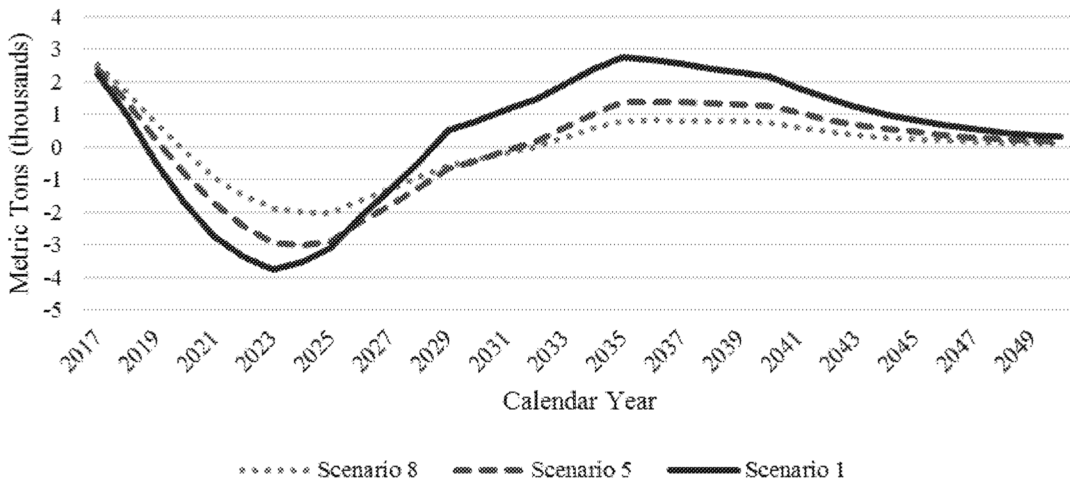
Table 20. Differences in NO_X Emissions (% Change) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	-0.04%	-0.15%	-0.33%
	Upstream	--	0.07%	0.12%	0.31%
	Total	--	**-0.01%**	**-0.09%**	**-0.18%**
2025	Tailpipe	--	-0.77%	-1.17%	-1.61%
	Upstream	--	0.64%	1.10%	2.01%
	Total	--	**-0.34%**	**-0.49%**	**-0.52%**
2030	Tailpipe	--	-0.91%	-1.48%	-2.04%
	Upstream	--	1.29%	2.25%	3.99%
	Total	--	**-0.10%**	**-0.10%**	**0.19%**
2035	Tailpipe	--	-0.44%	-0.77%	-1.07%
	Upstream	--	1.70%	2.92%	5.03%
	Total	--	**0.33%**	**0.56%**	**1.13%**
2040	Tailpipe	--	-0.10%	-0.21%	-0.30%
	Upstream	--	2.07%	3.58%	6.05%
	Total	--	**0.63%**	**1.06%**	**1.82%**
2045	Tailpipe	--	-0.11%	-0.12%	-0.11%
	Upstream	--	2.02%	3.70%	6.51%
	Total	--	**0.56%**	**1.08%**	**1.96%**
2050	Tailpipe	--	0.22%	0.30%	0.39%
	Upstream	--	2.23%	4.13%	7.44%
	Total	--	**0.84%**	**1.48%**	**2.57%**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Figure 8 provides a graphical presentation of the changes over time in NO_X emissions under the three alternative CAFE standards. The changes in NO_X emissions are due both to changes in tailpipe emissions and changes in upstream emissions. NO_X tailpipe emissions are lower for all three alternatives in most years, reflecting the accelerated scrappage of older vehicles under the less-stringent standards. In contrast, NO_X upstream emissions increase because of increases in gasoline transportation, distribution, and storage under the less-stringent standards. For the alternative standards, the net result is a pattern of net NO_X emissions that are lower relative to the augural standards baseline in earlier years (as tailpipe emissions reductions exceed upstream emissions increases) and higher in the later years (as upstream emissions increases exceed tailpipe emissions reductions). As with all effects, by the end of the period the net changes are small because MY 2029 and earlier motor vehicles become a small part of the vehicle fleet.

Figure 8. Differences in NO_X Emissions relative to Augural Standards Baseline by Calendar Year



2. Impacts on VOC Emissions

Table 30 provides our estimates of VOC emissions for each of the alternative scenarios as well as for the augural standards baseline. Note that due to a limitation of the MOVES model these estimates do not include changes in evaporative tailpipe VOC emissions. Note that the NHTSA/EPA PRIA notes that the agencies' analysis also does not include estimates of the evaporative emission from light-duty vehicles.[11]

[11] See p. 1303 of NHTSA/EPA PRIA (2018b)

Table 21. VOC Emissions (thousands of metric tons) for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	496.4	496.8	496.3	495.6
	Upstream	329.1	329.3	329.5	330.1
	Total	**825.5**	**826.1**	**825.8**	**825.7**
2025	Tailpipe	316.6	314.7	313.7	312.7
	Upstream	305.0	306.9	308.3	311.1
	Total	**621.6**	**621.7**	**622.0**	**623.7**
2030	Tailpipe	213.3	211.7	210.7	209.9
	Upstream	262.6	265.9	268.5	273.0
	Total	**475.8**	**477.7**	**479.2**	**483.0**
2035	Tailpipe	130.0	129.6	129.2	128.9
	Upstream	150.7	153.2	155.1	158.3
	Total	**280.7**	**282.8**	**284.3**	**287.2**
2040	Tailpipe	66.5	66.5	66.4	66.4
	Upstream	68.6	70.1	71.1	72.8
	Total	**135.1**	**136.5**	**137.5**	**139.2**
2045	Tailpipe	25.0	24.9	24.9	24.9
	Upstream	22.9	23.4	23.8	24.4
	Total	**47.9**	**48.3**	**48.7**	**49.4**
2050	Tailpipe	7.5	7.5	7.5	7.5
	Upstream	6.5	6.6	6.8	7.0
	Total	**14.0**	**14.2**	**14.3**	**14.5**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Table 22 and Table 23 provides our estimates of VOC emissions for each of the alternative scenarios relative to the augural standards baseline, expressed as differences and percentage differences.

Table 22. VOC Emissions (thousands of metric tons) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	0.4	-0.1	-0.8
	Upstream	--	0.2	0.4	1.0
	Total	--	**0.6**	**0.3**	**0.2**
2025	Tailpipe	--	-1.9	-2.9	-3.9
	Upstream	--	1.9	3.3	6.1
	Total	--	**0.1**	**0.4**	**2.1**
2030	Tailpipe	--	-1.5	-2.5	-3.3
	Upstream	--	3.4	5.9	10.5
	Total	--	**1.9**	**3.4**	**7.1**
2035	Tailpipe	--	-0.5	-0.8	-1.1
	Upstream	--	2.6	4.4	7.6
	Total	--	**2.1**	**3.6**	**6.5**
2040	Tailpipe	--	0.0	-0.1	-0.1
	Upstream	--	1.4	2.5	4.2
	Total	--	**1.4**	**2.4**	**4.0**
2045	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	0.5	0.9	1.5
	Total	--	**0.4**	**0.8**	**1.5**
2050	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	0.1	0.3	0.5
	Total	--	**0.2**	**0.3**	**0.5**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

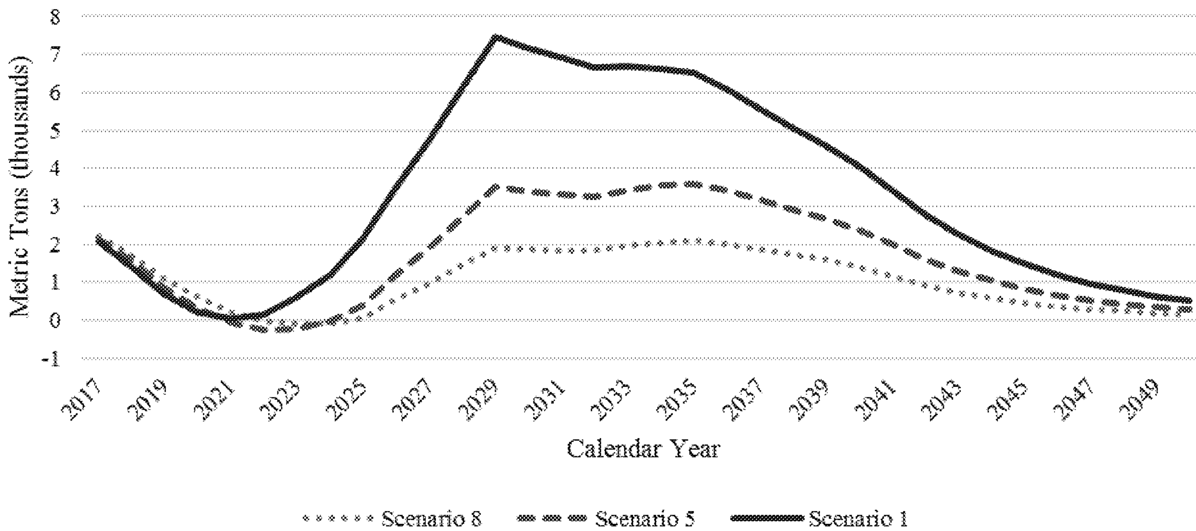
Table 23. VOC Emissions (% Change) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	0.08%	-0.01%	-0.16%
	Upstream	--	0.07%	0.12%	0.31%
	Total	--	**0.07%**	**0.04%**	**0.02%**
2025	Tailpipe	--	-0.59%	-0.92%	-1.25%
	Upstream	--	0.64%	1.09%	1.99%
	Total	--	**0.01%**	**0.06%**	**0.34%**
2030	Tailpipe	--	-0.72%	-1.18%	-1.57%
	Upstream	--	1.29%	2.25%	4.00%
	Total	--	**0.39%**	**0.71%**	**1.50%**
2035	Tailpipe	--	-0.36%	-0.64%	-0.85%
	Upstream	--	1.70%	2.93%	5.05%
	Total	--	**0.75%**	**1.28%**	**2.32%**
2040	Tailpipe	--	-0.04%	-0.12%	-0.18%
	Upstream	--	2.08%	3.60%	6.07%
	Total	--	**1.04%**	**1.77%**	**2.99%**
2045	Tailpipe	--	-0.07%	-0.07%	-0.04%
	Upstream	--	2.03%	3.71%	6.52%
	Total	--	**0.94%**	**1.74%**	**3.10%**
2050	Tailpipe	--	0.25%	0.34%	0.44%
	Upstream	--	2.23%	4.13%	7.44%
	Total	--	**1.17%**	**2.10%**	**3.69%**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Figure 9 provides a graphical presentation of the changes over time in VOC emissions under the three alternative CAFE standards. Tailpipe VOC emissions are lower for all three alternatives in most years, reflecting the accelerated scrappage of older vehicles under the less-stringent standards. The upstream VOC emissions are greater for all three alternatives, reflecting the increase in fuel consumption and associated upstream emissions due to the alternative standards. Combined, net VOC emissions are greater for all three alternatives after calendar year 2025, as the increases in upstream emissions exceed reductions in tailpipe emissions from scrappage effects.

Figure 9. Differences in VOC Emissions relative to Augural Standards Baseline by Calendar Year



3. Impacts on Particulate Matter Emissions

Table 24 provides our estimates of $PM_{2.5}$ emissions for each of the alternative scenarios as well as for the augural standards baseline.

Table 24. $PM_{2.5}$ Emissions (metric tons) for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	16,752.1	16,738.6	16,727.0	16,706.3
	Upstream	16,784.6	16,796.3	16,805.3	16,836.9
	Total	**33,536.8**	**33,534.9**	**33,532.3**	**33,543.2**
2025	Tailpipe	13,410.2	13,333.1	13,293.5	13,245.8
	Upstream	13,524.3	13,610.9	13,672.4	13,795.6
	Total	**26,934.5**	**26,944.0**	**26,965.9**	**27,041.4**
2030	Tailpipe	10,802.9	10,716.9	10,661.5	10,601.6
	Upstream	11,688.5	11,839.0	11,951.1	12,155.4
	Total	**22,491.4**	**22,555.9**	**22,612.6**	**22,757.0**
2035	Tailpipe	7,192.5	7,155.5	7,130.1	7,104.2
	Upstream	6,656.1	6,769.0	6,850.4	6,991.2
	Total	**13,848.6**	**13,924.4**	**13,980.5**	**14,095.4**
2040	Tailpipe	3,843.1	3,837.9	3,833.1	3,828.1
	Upstream	2,997.4	3,059.4	3,104.7	3,178.7
	Total	**6,840.5**	**6,897.3**	**6,937.9**	**7,006.8**
2045	Tailpipe	1,554.8	1,553.4	1,553.5	1,553.7
	Upstream	1,006.5	1,026.9	1,043.8	1,072.0
	Total	**2,561.3**	**2,580.3**	**2,597.3**	**2,625.7**
2050	Tailpipe	489.6	490.6	491.2	491.7
	Upstream	288.1	294.6	300.1	309.6
	Total	**777.7**	**785.1**	**791.2**	**801.3**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Table 25 and Table 26 provide our estimates of $PM_{2.5}$ emissions for each of the alternative scenarios relative to the augural standards baseline.

Table 25. $PM_{2.5}$ Emissions (metric tons) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	-13.6	-25.1	-45.9
	Upstream	--	11.7	20.7	52.2
	Total	--	**-1.9**	**-4.5**	**6.4**
2025	Tailpipe	--	-77.1	-116.8	-164.4
	Upstream	--	86.7	148.2	271.3
	Total	--	**9.5**	**31.4**	**106.9**
2030	Tailpipe	--	-86.0	-141.4	-201.3
	Upstream	--	150.5	262.6	466.8
	Total	--	**64.5**	**121.2**	**265.6**
2035	Tailpipe	--	-37.0	-62.4	-88.2
	Upstream	--	112.8	194.3	335.1
	Total	--	**75.8**	**131.9**	**246.8**
2040	Tailpipe	--	-5.2	-10.0	-15.0
	Upstream	--	62.1	107.4	181.4
	Total	--	**56.9**	**97.4**	**166.4**
2045	Tailpipe	--	-1.4	-1.3	-1.1
	Upstream	--	20.4	37.3	65.5
	Total	--	**19.0**	**36.0**	**64.4**
2050	Tailpipe	--	1.0	1.6	2.2
	Upstream	--	6.4	11.9	21.4
	Total	--	**7.4**	**13.5**	**23.6**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

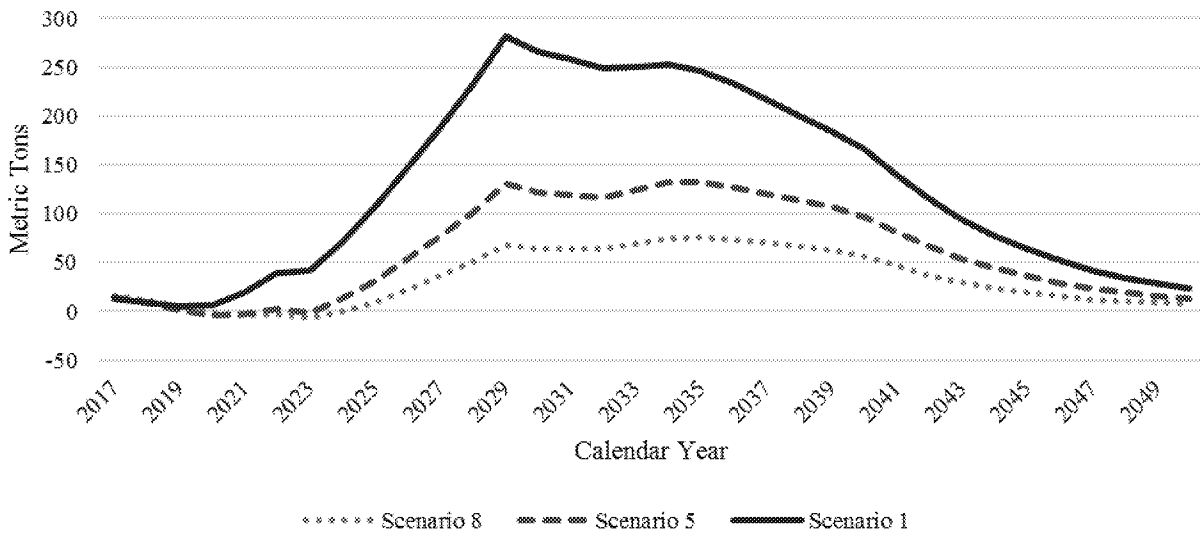
Table 26. $PM_{2.5}$ Emissions (% Change) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	-0.08%	-0.15%	-0.27%
	Upstream	--	0.07%	0.12%	0.31%
	Total	--	**-0.01%**	**-0.01%**	**0.02%**
2025	Tailpipe	--	-0.58%	-0.87%	-1.23%
	Upstream	--	0.64%	1.10%	2.01%
	Total	--	**0.04%**	**0.12%**	**0.40%**
2030	Tailpipe	--	-0.80%	-1.31%	-1.86%
	Upstream	--	1.29%	2.25%	3.99%
	Total	--	**0.29%**	**0.54%**	**1.18%**
2035	Tailpipe	--	-0.51%	-0.87%	-1.23%
	Upstream	--	1.69%	2.92%	5.03%
	Total	--	**0.55%**	**0.95%**	**1.78%**
2040	Tailpipe	--	-0.13%	-0.26%	-0.39%
	Upstream	--	2.07%	3.58%	6.05%
	Total	--	**0.83%**	**1.42%**	**2.43%**
2045	Tailpipe	--	-0.09%	-0.08%	-0.07%
	Upstream	--	2.02%	3.70%	6.51%
	Total	--	**0.74%**	**1.40%**	**2.51%**
2050	Tailpipe	--	0.20%	0.32%	0.44%
	Upstream	--	2.23%	4.13%	7.44%
	Total	--	**0.95%**	**1.74%**	**3.03%**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Figure 10 provides a graphical presentation of the changes over time in $PM_{2.5}$ emissions under the three alternative CAFE standards. The tailpipe $PM_{2.5}$ emissions are lower for all three alternatives in most years, reflecting the accelerated scrappage of older vehicles under the less-stringent standards. The upstream emissions are greater for all three alternatives, reflecting the increase in fuel consumption and associated fuel development emissions due to the alternative standards. The net impact on emissions indicates that the effects due to changes in fuel demand outweigh tailpipe $PM_{2.5}$ emissions impacts due to fleet age composition.

Figure 10. Differences in $PM_{2.5}$ Emissions relative to Augural Standards Baseline by Calendar Year



4. Impacts on SO_2 Emissions

Table 27 provides our estimates of SO_2 emissions for each of the alternative scenarios as well as for the augural standards baseline.

Table 27. SO_2 Emissions (metric tons) for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	6.5	6.5	6.5	6.5
	Upstream	186.8	186.9	187.0	187.4
	Total	**193.3**	**193.5**	**193.6**	**193.9**
2025	Tailpipe	5.8	5.8	5.8	5.8
	Upstream	130.5	131.3	131.9	133.1
	Total	**136.3**	**137.1**	**137.7**	**138.9**
2030	Tailpipe	4.9	4.8	4.8	4.8
	Upstream	112.5	113.9	115.0	117.0
	Total	**117.3**	**118.8**	**119.8**	**121.8**
2035	Tailpipe	2.8	2.8	2.8	2.8
	Upstream	63.8	64.9	65.7	67.0
	Total	**66.6**	**67.7**	**68.5**	**69.8**
2040	Tailpipe	1.3	1.3	1.3	1.3
	Upstream	28.6	29.2	29.7	30.4
	Total	**29.9**	**30.5**	**30.9**	**31.6**
2045	Tailpipe	0.4	0.4	0.4	0.4
	Upstream	9.6	9.8	9.9	10.2
	Total	**10.0**	**10.2**	**10.4**	**10.6**
2050	Tailpipe	0.1	0.1	0.1	0.1
	Upstream	2.7	2.8	2.8	2.9
	Total	**2.9**	**2.9**	**3.0**	**3.1**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Table 28 and Table 29 provide our estimates of SO_2 emissions for each of the alternative scenarios as well as for the augural standards baseline.

Table 28. SO_2 Emissions (metric tons) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	0.1	0.2	0.6
	Total	--	**0.1**	**0.2**	**0.6**
2025	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	0.8	1.4	2.6
	Total	--	**0.8**	**1.4**	**2.6**
2030	Tailpipe	--	0.0	0.0	-0.1
	Upstream	--	1.4	2.5	4.5
	Total	--	**1.4**	**2.5**	**4.4**
2035	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	1.1	1.9	3.2
	Total	--	**1.1**	**1.8**	**3.2**
2040	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	0.6	1.0	1.7
	Total	--	**0.6**	**1.0**	**1.7**
2045	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	0.2	0.4	0.6
	Total	--	**0.2**	**0.4**	**0.6**
2050	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	0.1	0.1	0.2
	Total	--	**0.1**	**0.1**	**0.2**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

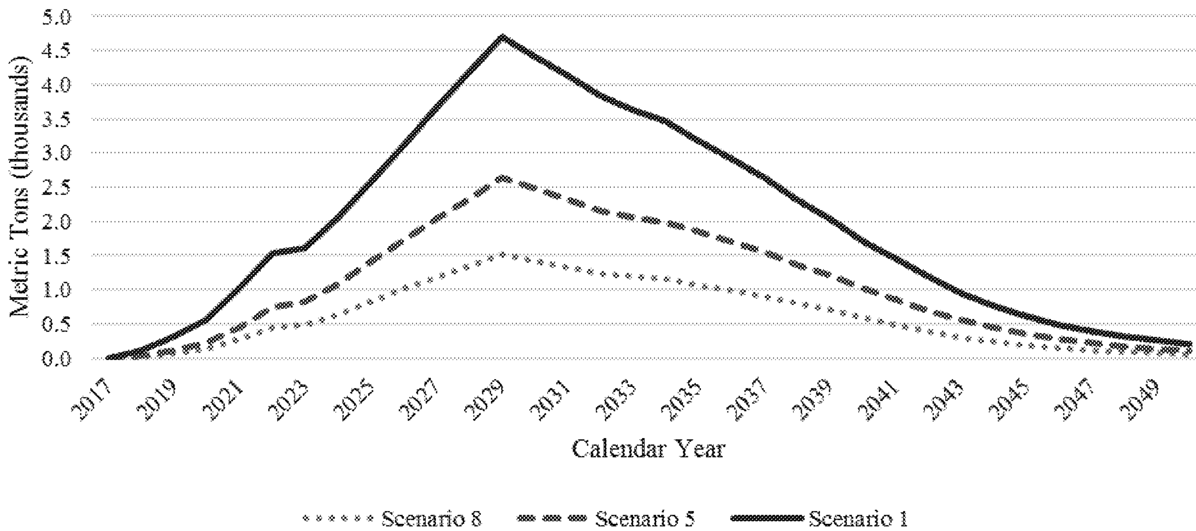
Table 29. SO_2 Emissions (% Change) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	-0.06%	-0.08%	-0.15%
	Upstream	--	0.07%	0.12%	0.31%
	Total	--	**0.06%**	**0.12%**	**0.29%**
2025	Tailpipe	--	-0.35%	-0.54%	-0.82%
	Upstream	--	0.64%	1.10%	2.01%
	Total	--	**0.60%**	**1.03%**	**1.89%**
2030	Tailpipe	--	-0.51%	-0.85%	-1.34%
	Upstream	--	1.29%	2.25%	3.99%
	Total	--	**1.21%**	**2.12%**	**3.77%**
2035	Tailpipe	--	-0.31%	-0.52%	-0.82%
	Upstream	--	1.69%	2.92%	5.03%
	Total	--	**1.61%**	**2.77%**	**4.79%**
2040	Tailpipe	--	-0.03%	-0.06%	-0.15%
	Upstream	--	2.07%	3.58%	6.05%
	Total	--	**1.98%**	**3.43%**	**5.78%**
2045	Tailpipe	--	-0.01%	0.06%	0.11%
	Upstream	--	2.02%	3.70%	6.51%
	Total	--	**1.94%**	**3.55%**	**6.23%**
2050	Tailpipe	--	0.18%	0.29%	0.40%
	Upstream	--	2.23%	4.13%	7.44%
	Total	--	**2.14%**	**3.97%**	**7.14%**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Figure 11 provides a graphical presentation of the changes over time in SO_2 emissions under the three alternative CAFE standards. Tailpipe SO_2 emissions are lower for all three alternatives in most years, reflecting the accelerated scrappage of older vehicles under the less-stringent standards. The upstream emissions are greater for all three alternatives, reflecting the increase in fuel consumption and associated upstream emissions due to the alternative standards. The net increase in emissions for all calendar years indicates that the upstream SO_2 impacts from changes in fuel demand outweigh the effects due to fleet age composition, as tailpipe emissions for SO_2 are relatively small.

Figure 11. Differences in SO_2 Emissions relative to Augural Standards Baseline by Calendar Year



5. Impacts on Carbon Monoxide Emissions

Table 21 provides our estimates of CO emissions for each of the alternative scenarios as well as for the augural standards baseline.

Table 30. CO Emissions (thousands of metric tons) for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	9,036.9	9,031.5	9,025.1	9,013.7
	Upstream	97.3	97.4	97.4	97.6
	Total	**9,134.2**	**9,128.9**	**9,122.5**	**9,111.3**
2025	Tailpipe	6,792.1	6,752.4	6,731.7	6,707.7
	Upstream	87.7	88.2	88.6	89.4
	Total	**6,879.8**	**6,840.7**	**6,820.4**	**6,797.1**
2030	Tailpipe	4,862.7	4,822.9	4,797.2	4,770.6
	Upstream	76.0	77.0	77.7	79.1
	Total	**4,938.7**	**4,899.9**	**4,874.9**	**4,849.7**
2035	Tailpipe	2,997.4	2,982.7	2,972.3	2,962.0
	Upstream	43.6	44.4	44.9	45.8
	Total	**3,041.0**	**3,027.1**	**3,017.2**	**3,007.8**
2040	Tailpipe	1,478.1	1,476.4	1,474.5	1,472.6
	Upstream	19.7	20.1	20.4	20.9
	Total	**1,497.9**	**1,496.5**	**1,494.9**	**1,493.6**
2045	Tailpipe	544.3	543.6	543.5	543.5
	Upstream	6.6	6.7	6.9	7.0
	Total	**550.9**	**550.3**	**550.4**	**550.5**
2050	Tailpipe	160.8	161.1	161.3	161.5
	Upstream	1.9	1.9	2.0	2.0
	Total	**162.7**	**163.1**	**163.3**	**163.5**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Table 31 and Table 32 provides our estimates of CO emissions for each of the alternative scenarios relative to the augural standards baseline.

Table 31. CO Emissions (thousands of metric tons) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	-5.4	-11.8	-23.2
	Upstream	--	0.1	0.1	0.3
	Total	--	**-5.4**	**-11.7**	**-22.9**
2025	Tailpipe	--	-39.7	-60.4	-84.4
	Upstream	--	0.6	1.0	1.8
	Total	--	**-39.2**	**-59.4**	**-82.7**
2030	Tailpipe	--	-39.8	-65.5	-92.0
	Upstream	--	1.0	1.7	3.0
	Total	--	**-38.8**	**-63.8**	**-89.0**
2035	Tailpipe	--	-14.6	-25.1	-35.4
	Upstream	--	0.7	1.3	2.2
	Total	--	**-13.9**	**-23.8**	**-33.2**
2040	Tailpipe	--	-1.8	-3.6	-5.5
	Upstream	--	0.4	0.7	1.2
	Total	--	**-1.4**	**-2.9**	**-4.3**
2045	Tailpipe	--	-0.7	-0.8	-0.8
	Upstream	--	0.1	0.2	0.4
	Total	--	**-0.6**	**-0.5**	**-0.3**
2050	Tailpipe	--	0.3	0.5	0.6
	Upstream	--	0.0	0.1	0.1
	Total	--	**0.4**	**0.5**	**0.8**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

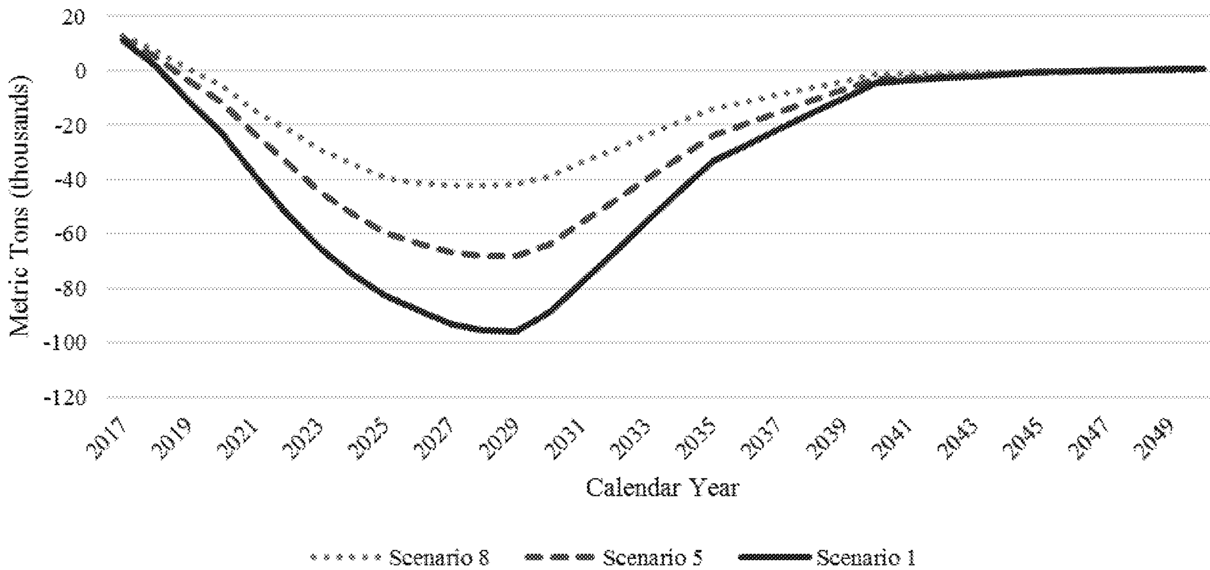
Table 32. CO Emissions (% Change) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	-0.06%	-0.13%	-0.26%
	Upstream	--	0.07%	0.12%	0.31%
	Total	--	**-0.06%**	**-0.13%**	**-0.25%**
2025	Tailpipe	--	-0.58%	-0.89%	-1.24%
	Upstream	--	0.64%	1.09%	2.00%
	Total	--	**-0.57%**	**-0.86%**	**-1.20%**
2030	Tailpipe	--	-0.82%	-1.35%	-1.89%
	Upstream	--	1.29%	2.25%	4.00%
	Total	--	**-0.79%**	**-1.29%**	**-1.80%**
2035	Tailpipe	--	-0.49%	-0.84%	-1.18%
	Upstream	--	1.70%	2.93%	5.04%
	Total	--	**-0.46%**	**-0.78%**	**-1.09%**
2040	Tailpipe	--	-0.12%	-0.24%	-0.37%
	Upstream	--	2.08%	3.59%	6.06%
	Total	--	**-0.09%**	**-0.19%**	**-0.29%**
2045	Tailpipe	--	-0.13%	-0.14%	-0.14%
	Upstream	--	2.03%	3.71%	6.52%
	Total	--	**-0.10%**	**-0.09%**	**-0.06%**
2050	Tailpipe	--	0.19%	0.29%	0.39%
	Upstream	--	2.23%	4.14%	7.44%
	Total	--	**0.22%**	**0.34%**	**0.48%**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Figure 9 provides a graphical presentation of the changes over time in CO emissions under the three alternative CAFE standards. The CO tailpipe emissions are lower for all three alternatives in most years, reflecting the accelerated scrappage of older vehicles under the less-stringent standards. The upstream emissions are greater for all three alternatives, reflecting the increase in fuel consumption and associated upstream emissions due to the alternative standards. The net impact on emissions indicates that the CO decreases due to fleet age composition outweigh the emissions increases due to changes in fuel demand.

Figure 12. Differences in CO Emissions relative to Augural Standards Baseline by Calendar Year



IV. Social Costs of Alternative CAFE Standards

This chapter uses the results of the fleet population, VMT, and emissions modeling summarized in the previous chapter, along with other parameters, [12] to develop estimates of the social costs of the three alternative CAFE standards. As with the social benefit estimates provided in the next chapter, we rely on sound cost-benefit methodology based on the existing academic literature (see, e.g., Boardman et al. 2011) and the relevant EPA guidelines (EPA 2014).

We include the following four social cost categories:

1. *New vehicle technology costs.* These costs include the costs of the technologies to achieve compliance with the various CAFE standards.
2. *Congestion costs.* Changes in VMT lead to changes in the congestion costs that motorists incur on the road.
3. *Noise costs.* Changes in VMT lead to changes in the noise levels that motorists experience.
4. *Crash costs.* Changes in the vehicle fleet and VMT lead to changes in fatal and non-fatal crash costs.

All values reported in this chapter and the next are present values over the period from 2017 to 2050 (in billions of 2016 dollars) as of January 1, 2017, based upon information for model years through MY 2029, using both 3% and 7% discount rates.

A. New Vehicle Technology Costs

This section assesses the social costs of the additional technologies adopted for new vehicles to achieve compliance with the CAFE standard alternatives, as estimated by Trinity using the latest version of the CAFE Model developed by the DOT. Technology costs represent the additional costs borne by consumers who pay for these technologies in the form of higher vehicle prices. Below, we discuss the methodology for estimating these costs. We then present estimates of the difference in technology costs for each of the three CAFE alternatives compared to the augural standards.

1. Methodology

CAFE standards lead automobile manufacturers to incorporate additional fuel-efficiency-enhancing technologies into their vehicles. The specific technologies adopted by manufacturers are estimated in the CAFE Model, which assumes that manufacturers minimize the effective cost of technology application on a group of vehicles. This minimization accounts for the cost of all potential technologies, the value to consumers of fuel savings due to the technologies, and the effects of non-compliance costs (CAFE fines). Note that the CAFE Model was adapted for this

[12] We rely upon many parameters developed by EPA and NHTSA, most of which are described in the PRIA. We have not developed independent assessments of these parameters. The same caveat applies to parameters discussed in this chapter and the next (and in appendices) related to valuation of congestion, noise, crash costs, compliance costs, petroleum market externalities, GHG emissions, and conventional pollutant emissions.

study by Trinity. For information on the CAFE Model and its implementation for this study, see Appendix A.

We apply the technology cost estimates from the CAFE Model to the changes in sales for new vehicles in the New Vehicle Market Model, which estimates the sales impacts of alternative CAFE standards relative to the augural standards. Based on the projected changes in sales estimated in the New Vehicle Market Model and the technology costs as estimated in the CAFE Model, we estimate the technology cost savings for each of the less-stringent CAFE alternatives compared to the augural standards.

2. Results

Table 33 summarizes our estimates of the reductions in technology costs under the three alternative CAFE standards. Values for each of the alternative CAFE standards are relative to the augural standards baseline.

Table 33. Technology Costs Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Technology Costs	-$68.8	-$51.8	-$113.9	-$85.4	-$170.7	-$128.5

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.
Source: NERA/Trinity calculations as explained in text.

B. Congestion Costs

This section reports estimates of the changes in congestion costs due to the three alternative CAFE standards. Congestion cost increases arise from increases in VMT, with dollar values based on delay costs that are imposed on other drivers (thus creating an external effect). We first discuss our methodology, which is based on the methodology developed by NHTSA/EPA as described in the PRIA. We then present estimates of the congestion costs for the three alternatives relative to the augural standards baseline based on the results of our fleet population and VMT modeling.

1. Methodology

To assess the external congestion costs, we rely on estimates of congestion costs in dollars per mile ($/mile) for passenger cars and light trucks developed by the U.S. Federal Highway Administration (FHWA).[13] This parameter from FHWA represents the marginal congestion cost resulting from a unit increase in VMT. The marginal congestion cost estimates are intended to capture the costs due to added delays to other motorists associated with an additional mile traveled. FHWA has developed separate estimates for different vehicle types and for "rural" vs "urban" highway types. For a representative national value, our analysis relies on the estimates

[13] Federal Highway Administration, 1997 Highway Cost Allocation Study, Chapter V, Tables V-22 and V-23. These values were updated to 2016 dollars using the change in the Implicit Price Deflator for U.S. Gross Domestic Product, reported in U.S. Bureau of Economic Analysis, National Income and Product Accounts, Table 1.1.9.

developed by FHWA for the "Automobiles" and "Pickup and Vans" categories for the "All Highways" type.

These congestion values are summarized in Table 34. Note that these are the same values relied on by NHTSA/EPA in the PRIA.

Table 34. Marginal External Costs of Congestion (2016$/mile)

	Passenger Car	Light Truck
External Cost of Congestion	$0.0608	$0.0543

Note: Values in 2016$.
Source: Values originally developed by FHWA (1997) as cited in NHTSA/EPA (2018b).

We develop estimates of the additional external congestion costs of the three alternative CAFE standards by multiplying the values in Table 34 by the estimates of changes in VMT by vehicle type (i.e., passenger car and light truck) based upon our fleet population and VMT modeling.

2. Results

Table 35 summarizes our estimates of congestion costs for the alternative standards relative to the augural standards baseline. As shown in Table 35, the congestion costs are lower for each of the alternative standards relative to the augural standards baseline. This result is consistent with the VMT results reported in Figure 6, which show estimates of decreases in VMT due to the alternative standards. The VMT results reflect the change in the fleet age distribution (due to the scrappage effect) as well as the rebound effect.

Table 35. Congestion Costs Relative Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Congestion Costs	-$6.3	-$3.9	-$10.6	-$6.5	-$17.9	-$10.9

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.
Source: NERA/Trinity calculations as explained in text

C. Noise Costs

In this section, we develop estimates of the external costs due to noise associated with the three alternative standards. We first include a discussion of our methodology, which we develop based on NHTSA's methodology as described in the PRIA. We then present results for estimates of the noise impacts based on the results of our fleet population and VMT modeling.

1. Methodology

To assess the external noise costs, we rely on estimates of noise costs in dollars per mile ($/mile) developed by the FHWA.[14] These parameters were developed using the FHWA noise model, which estimates the loss in residential property value associated with exposure to increased noise levels. FHWA has developed separate estimates for different vehicle types and for "rural" vs "urban" highway types. For representative national values, our analysis relies on the estimates developed by FHWA for the "Automobiles" and "Pickup and Vans" categories for the "All Highways" type.

Note that the values reported for automobiles and pickups/vans is the same, so we use a single value for all vehicles in our evaluation. The value we use is shown in Table 36. This is the same valuation parameter relied on by NHTSA/EPA in the PRIA.

Table 36. Marginal External Costs of Noise (2016$/mile)

	Passenger Car	Light Truck
External Cost of Noise	$0.0008	$0.0008

Note: Values in 2016$.
Source: Values originally developed by FHWA (1997) as cited in NHTSA/EPA (2018b).

We develop estimates of the external noise costs due to the alternative standards by multiplying the values summarizes in Table 36 by the estimates of VMT we obtain from our fleet population and VMT modeling.

2. Results

Table 37 summarizes our estimates of changes in noise costs for the alternative CAFE standards relative to the augural standards baseline. As shown in Table 37, the noise costs are lower for each of the alternative standards relative to the augural standards baseline. This result is consistent with the VMT results reported in Figure 6, which show estimates of decreases in VMT due to the alternative standards. The VMT results reflect the change in the fleet age distribution (due to the scrappage effect) as well as the rebound effect.

Table 37. Noise Costs Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Noise Costs	-$0.1	-$0.1	-$0.2	-$0.1	-$0.3	-$0.2

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.
Source: NERA/Trinity calculations as explained in text

[14] Federal Highway Administration, 1997 Highway Cost Allocation Study, Chapter V, Tables V-22 and V-23. These values were updated to 2016 dollars using the change in the Implicit Price Deflator for U.S. Gross Domestic Product, reported in U.S. Bureau of Economic Analysis, National Income and Product Accounts, Table 1.1.9.

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D. Crash Costs

This section provides estimates of the changes in crash costs due to the three alternative CAFE standards. We first include a brief discussion of our methodology, which we develop based on the methodology described in the PRIA. We then present results for estimates of the crash impacts based on the results of our fleet population modeling and VMT modeling. For additional information related to our methodology for estimating crash costs, please refer to Appendix I.

1. Methodology

We develop estimates of the crash costs due to the alternative standards based on the methodology used in the PRIA. This methodology includes three effects of CAFE standards on crash costs, the following two of which we use: (a) VMT effects, with more miles increasing the likelihood of a crash; (b) age distribution effects, with a greater proportion of newer vehicles decreasing the chance of a crash based upon improvements over time in safety features. The PRIA includes a third effect related to changes in the curb weight of vehicles in the fleet that is based on analysis of the link between vehicle curb weights and fatality risks. None of the estimates of that link were statistically significant in the PRIA analysis. Because of the lack of statistical significance of this effect and the conclusion in the PRIA that the effect of curb weight effects are small relative to the other two effects on crash costs,[15] we do not include effects of vehicle mass in our estimation of changes in crash costs.

We estimate fatal crash costs for non-rebound miles using the same modeling framework used in the PRIA. As in the PRIA, we then estimate non-fatal crash costs using a scalar that measures the average relationship between total fatal and total non-fatal crash costs. For details on the methodology we use to estimate crash costs, see Appendix I.

Note that we do not include crash costs associated with rebound miles in our social cost estimates, following the assumption in the PRIA that drivers internalize the safety risks of those additional miles and receive an offsetting private benefit of equal magnitude. Appendix I summarizes the explanation for this assumption in the PRIA and discusses considerations that this assumption might lead to understating changes in social costs related to vehicle crashes.

2. Results

Table 38 summarizes our estimates of changes in crash costs for the alternative standards relative to the augural standards baseline, including fatal and non-fatal crash costs. As shown in Table 38, the crash costs are lower for each of the alternative standards relative to the augural standards baseline. The reduction in crash costs is greatest for Scenario 5 and smallest for Scenario 1. This pattern reflects empirical estimates of the two competing effects of the less stringent standards on crash costs. On the one hand, the less-stringent standards lead to a newer fleet (more new vehicles and fewer existing vehicles) that has a higher average level of safety features. On the other hand, the less stringent standards result in more non-rebound VMT (as newer vehicles are driven more miles). Under Alternative 1, the higher non-rebound VMT more closely offsets the

[15] Table 11-24 on p. 1414 of PRIA.

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safety benefits of newer vehicles than under Alternatives 5 and 8, resulting in a smaller difference in crash costs relative to the augural standards than the other two alternatives.

Table 38. Crash Costs Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Fatal Crash Costs	-$1.1	-$0.9	-$1.3	-$1.1	-$1.0	-$1.0
Non-Fatal Crash Costs	-$1.5	-$1.2	-$1.7	-$1.4	-$1.3	-$1.3
Total	**-$2.6**	**-$2.1**	**-$3.0**	**-$2.5**	**-$2.3**	**-$2.3**

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.

Source: NERA/Trinity calculations as explained in text.

E. Summary of Social Costs

Table 39 shows the estimated social costs of the three CAFE alternatives using 3 percent and 7 percent discount rates. The values include effects for model year vehicles up to MY 2029 based on results in calendar years from 2017 to 2050. Because the baseline ("no action" alternative) is the most stringent set of standards (augural standards), as noted above, the values for social costs for the three less-stringent CAFE standards evaluated are all negative, i.e., the values show the cost savings from the three less-stringent CAFE standards.

Table 39. Social Costs Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
Social Cost Category	**3%**	**7%**	**3%**	**7%**	**3%**	**7%**
Technology Costs	-$68.8	-$51.8	-$113.9	-$85.4	-$170.7	-$128.5
Congestion Costs	-$6.3	-$3.9	-$10.6	-$6.5	-$17.9	-$10.9
Noise Costs	-$0.1	-$0.1	-$0.2	-$0.1	-$0.3	-$0.2
Fatal Crash Costs	-$1.1	-$0.9	-$1.3	-$1.1	-$1.0	-$1.0
Non-Fatal Crash Costs	-$1.5	-$1.2	-$1.7	-$1.4	-$1.3	-$1.3
Total	**-$77.7**	**-$57.8**	**-$127.7**	**-$94.5**	**-$191.2**	**-$141.8**

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. Values may not sum to totals due to rounding.

Source: NERA/Trinity calculations as explained in text.

V. Social Benefits of Alternative CAFE Standards

This chapter provides estimates of the social benefits of the alternative CAFE standards. We include the following five social benefit categories.

1. *Fuel economy benefits.* Improvements in fuel economy reduce the cost of travel, leading to lower fuel expenditures, increased travel, and less time spent refueling. We use the New Vehicle Market Model's estimate of consumers' willingness to pay for a reduction in cost per mile to calculate the dollar value to consumers of the CAFE Model's estimated changes in vehicles' fuel economies. These estimates are supplemented by estimates of the value of changes in VMT and the value of differences in time spent refueling.

2. *Fuel tax revenue benefits.* Changes in fuel expenditures lead to changes in tax revenue collected from motor fuel sales. Note that fuel tax payments are part of consumer fuel expenditures, which are a component of consumers' valuation of fuel economy changes.

3. *Petroleum market externality benefits.* Changes in gasoline demand would lead to changes in the domestic and global petroleum markets, which could have an external effect beyond the effects experienced by new vehicle purchasers.

4. *Greenhouse gas emissions benefits.* Changes in VMT and (to a lesser extent) changes in the vehicle fleet affect GHG tailpipe emissions, and changes in fuel use lead to changes in upstream GHG emissions.

5. *Criteria pollutant emissions benefits.* Changes in the vehicle fleet and VMT lead to changes in tailpipe emissions of criteria pollutants, and changes in fuel use lead to changes in upstream emissions. We develop dollar values of these changes for emissions of nitrogen oxides (NOx), volatile organic compounds (VOC), particulate matter ($PM_{2.5}$), and sulfur dioxide (SO_2).[16]

Results are presented using both 3 percent and 7 percent discount rates. All values are present values over the period from 2017 to 2050 as of January 1, 2017, based upon information for model years up to MY 2029.

A. Fuel Economy Benefits

This section provides estimates of changes in the benefits to consumers of the fuel economy changes due to the three CAFE standard alternatives. Vehicles with greater fuel economy provide value to consumers. Most directly, the improved fuel efficiency translates into fuel savings for consumers for a given distance of travel. The decreased fuel costs also result in consumers driving more miles due to the rebound effect, however, which partially offsets those fuel savings but provides additional consumers surplus through increased mobility. Finally,

[16] Values for CO emissions are not available from the sources we relied upon for dollar-per-ton values. We note that impacts of CO emissions are highly-site specific because of little atmospheric distribution (e.g., primarily affect concentrations near roadways).

greater driving range of more fuel-efficient vehicles leads to less time spent refueling, providing consumers time savings as well.

1. Methodology

We develop estimates for the three ways in which changes in fuel economy can result in changes in consumer benefits.

a. Valuation of Fuel Economy Changes to New Vehicle Purchasers

The first component of our estimate of consumers' benefit of fuel economy improvements is the consumers' own valuation of expected fuel savings. The CAFE Model provides estimates of the changes in fuel efficiency that vehicles will achieve towards compliance in each CAFE standard alternative. We estimate consumers' willingness-to-pay for a unit decrease in fuel costs per mile in the New Vehicle Market Model based on observed market shares, vehicle attributes, and vehicle prices between 2013 and 2017 (for more details on the New Vehicle Market Model, see Appendix B). We combine this valuation from the New Vehicle Market Model with the CAFE Model results on changes in fuel economy to develop dollar values of the changes in benefits to consumers of the fuel economy changes under the three CAFE standard alternatives.

b. Valuation of Changes in VMT

We also estimate the changes in consumer surplus from the changes in mobility due to differences in fuel economy. As noted above, based on the rebound effect, consumers would change the miles they drive based upon changes in the cost-per-mile of travel. From a baseline level of miles, the decrease in cost-per-mile causes drivers to increase VMT until the marginal benefit of an additional mile decreases sufficiently to once again equal the marginal cost of the next mile. Over this range of "rebound miles," consumers would gain because the cost of those miles is less than the value of those additional miles.

c. Valuation of Changes in Driving Range

Finally, changes in the fuel efficiency of vehicles will affect the driving range for a given quantity of fuel (assuming the size of gas tanks does not change). We follow the NHTSA/EPA PRIA formulation for estimating changes in the benefits of reduced refueling time, based on assumptions about the frequency of refueling, the time spent each refuel, and the value of that time.

2. Results

Table 40 summarizes our estimates of changes in the fuel economy benefits owing to the alternative standards. Values for each of the alternative standards are relative to the augural standards baseline. Because the CAFE alternatives result in decreases in fuel economy, the results all show decreases in benefits related to fuel economy for vehicles subject to the alternative CAFE standards.

Table 40. Fuel Economy Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Valuation of Fuel Cost Savings	-$16.7	-$12.4	-$28.9	-$21.3	-$51.3	-$38.0
Rebound Mobility Benefit	-$9.7	-$5.8	-$17.4	-$10.3	-$31.0	-$18.5
Refueling Time Benefit	-$1.6	-$0.9	-$2.7	-$1.6	-$4.9	-$2.9
Benefits of Fuel Economy Changes	**-$28.0**	**-$19.1**	**-$49.0**	**-$33.3**	**-$87.2**	**-$59.5**

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.

Source: NERA/Trinity calculations as explained in text.

B. Fuel Tax Revenue Benefits

Our methodology for estimating the benefit consumers receive from the improved fuel efficiency includes changes in consumers' valuation of prospective fuel savings from improvements. Since those prospective fuel savings include foregone fuel tax payments, however, it is important to estimate the counter-acting change in fuel tax revenues. This section describes our methodology for estimating the change in fuel tax revenue and presents estimates of the differences in revenue collections for the CAFE alternatives compared to the augural standards.

1. Methodology

The fuel taxes collected in each scenario are computed by calculating motor fuel consumption in each scenario based on VMT by fuel type and applying the appropriate tax rates. We apply the same fuel taxes used in the NHTSA/EPA PRIA analysis, which include federal, state, and local tax rates.

2. Results

Table 41 summarizes our estimates of changes in the fuel tax revenue benefits due the alternative standards. Values for each of the alternative standards are relative to the augural standards baseline. Because fuel consumption is estimated to be greater under the alternative CAFE standards, the fuel tax revenues would be greater under the three alternatives than under the augural standards.

Table 41. Fuel Tax Revenue Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Fuel Tax Revenue Benefits	$4.3	$2.6	$7.4	$4.4	$13.2	$8.0

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.

Source: NERA/Trinity calculations as explained in text.

C. Petroleum Market Externality Benefits

Changes in the demand for gasoline can lead to market externalities associated with an oil security premium. Indeed, concerns for the oil price shocks and supply disruptions in the 1970s were major factors leading to efforts to reduce U.S. petroleum demand and dependence on oil imports. In this section, we evaluate various potential sources of externalities related to U.S. petroleum demand and provide recent estimates of the likely "oil security premium" based upon the existing literature. We present results for estimates of the petroleum market externalities based upon estimates of the "oil security premium" and estimated changes in domestic and imported oil under the three CAFE alternatives. Appendix J provides more detailed information related to our methodology and results for the potential petroleum market and energy security externalities, including a sensitivity that considers alternative estimates of the oil security premium.

1. Methodology

Drawing on the discussion provided by NHTSA/EPA in the PRIA, we evaluate the impact of the alternative standards on petroleum market externality benefits through consideration of three potential factors:

1. U.S. petroleum demand and its effect on global prices;
2. Macroeconomic costs of U.S. petroleum consumption (i.e., effect of price shocks); and
3. Potential effects of fuel consumption and petroleum imports on U.S. military spending.

Consistent with the conclusion in the PRIA as well as in the recent literature as summarized in Brown (2018), we develop estimates of petroleum market externalities based only on the second of these three potential factors. The basis for this conclusion is discussed in Appendix J.

We develop monetary estimates for this category by multiplying estimates of changes in domestic and imported crude oil demand due to the alternative standards—which are based on our estimates of change in fuel consumption as summarized in Figure 6—by estimates of oil security premiums developed by Brown (2018). Brown (2018) provides separate estimates of the petroleum externality cost due to changes in imported and domestic oil consumption. These values are provided in Table 42 below for the full group of studies used by Brown (2018), which include both "older" and "newer" studies. We rely on the NHTSA/EPA PRIA assumptions for the relative shares of domestic and imported crude oil. Appendix J includes sensitivity results using the NHTSA/EPA PRIA values for oil security premiums (from the CAFE Model documentation and analysis files) as well as alternatives based upon use of both the "newer" and the "older" studies to show the effects of more recent estimates.

Table 42. Changes in Expected Cost of Petroleum Price Shocks from Increased Fuel Consumption (2016$/barrel)

	Consumption of Imported Oil	Consumption of Domestic Oil
Petroleum Price Shock Externality	$4.88	$3.74

Note: Values in 2016 dollars per barrel. Dollar year conversions based on implicit GDP deflator information from BEA.
Source: "PVL-C" values from Table 9 from Brown (2018).

2. Results

Table 43 summarizes our estimates of the reductions in petroleum market external benefits due the alternative standards. Values for each of the alternative standards are relative to the augural standards baseline.

Table 43. Petroleum Market Externality Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Petroleum Market Externality Benefits	-$1.3	-$0.8	-$2.2	-$1.3	-$3.9	-$2.3

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.
Source: NERA/Trinity calculations as explained in text.

D. Greenhouse Gas Emission Benefits

This section provides information on the potential changes in GHG reduction benefits due to the alternative CAFE standards. We first include a brief discussion of our methodology for developing dollar values—which are referred to as the Social Cost of Carbon (SCC)—that is based on NHTSA's methodology as described in the PRIA, which in turn is based upon an earlier EPA study. We then present results for estimates of the GHG emissions reduction benefits based on the results of our emissions modeling. For detailed information related to our methodology for valuing changes in GHG emissions please refer to Appendix K. Note that Appendix K also provides results for sensitivity cases that uses alternative estimates of the SCC.[17]

1. Methodology

We develop estimates of the GHG reduction benefits by applying estimates of the SCC—as estimated by EPA in 2017 as part of its assessment of the Clean Power Plan (CPP)—to our estimates of changes in GHG emissions. The SCC values we use in the main analysis are those

[17] See NERA (2018) for information on alternative estimates of the social costs of carbon and effects on the PRIA net benefit estimates.

included in the PRIA, which are based upon the domestic values reported in the CPP RIA for both 3% and 7% discount rates. These values are provided in Table 44 below. NHTSA/EPA note in the PRIA that they include domestic values only based on guidance from OMB Circular A-4 that the scope of the analysis “should focus on benefits and costs that accrue to citizens and residents of the United States.[18] The derivation of these SCC values is explained in Appendix K, which also includes SCC estimates based upon the global values estimated by EPA in the CPP RIA (2017).

Table 44. Social Costs of Carbon Values (2016$/metric ton)

	Discount Rate	
Year	**3.0%**	**7.0%**
2015	$6	$1
2020	$7	$1
2025	$7	$1
2030	$8	$1
2035	$9	$2
2040	$9	$2
2045	$10	$2
2050	$11	$2

Note: Values rounded to nearest whole dollar. For ease of exposition table includes annual values at five-year increments. Note that the actual analysis relies on annual-specific values for all relevant years as provided in the CAFE Model parameters file available on the NHTSA website.
Source: Table 8-24 from NHTSA/EPA PRIA (2018b); CAFE Model analysis parameters file available on the NHTSA website.

We develop estimates of changes in the GHG reductions benefits due to the three alternative CAFE standards by multiplying the SCC values in Table 44 by the GHG emissions estimates, expressed as CO_2 equivalents.

2. Results

Table 45 summarizes our estimates of the changes in GHG damage reductions benefits due the alternative standards. Values for each of the alternative standards are relative to the augural standards baseline. Appendix K provides the results of a sensitivity case in which SCC values are based on EPA’s estimates of global rather than domestic impacts.

Table 45. CO_2 Reduction Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	**7%**	**3%**	**7%**	**3%**	**7%**
GHG Damage Reduction Benefits	-$1.6	-$0.2	-$2.9	-$0.3	-$7.1	-$0.7

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. GHG damage reduction benefits values include benefits associated CO_2, as well as other GHG pollutants, which have been converted to CO_{2eq}.
Source: NERA/Trinity calculations as explained in text.

[18] P. 15 of OMB Circular A-4 as cited by NHTSA/EPA (2018b) on p. 1068 of the PRIA.

E. Criteria Pollutant Emissions Benefits

This section considers the dollar values of benefits for changes in emissions of four criteria pollutants: NO_X, VOC, $PM_{2.5}$, and SO_2. We first provide a brief discussion of the information we relied upon for dollar benefit-per-ton values for emissions for tailpipe and upstream emissions. We then present estimated dollar values for the changes in criteria pollutant emissions based on the results of our emissions modeling. For detailed information on the information used to value changes in criteria emissions, see Appendix L.

1. Methodology

To value changes in criteria pollutant emissions we rely primarily on a recent EPA study of the dollar benefits-per-ton of reduced emissions (EPA 2018).[19] Estimates of criteria pollutant benefits are based upon multiplying the estimates of changes in pollutant tons by the national dollar-per-ton values. EPA (2018) reports dollar values based on air emissions modeling, population exposure modeling, dose-response functions for various health effects, and dollar values of these various health effects that are developed in a 2017 version of its environmental Benefits Mapping and Analysis Program—Community Edition (BenMAP-CE). EPA (2018) provides dollar-per-ton values for NO_X, SO_2, and $PM_{2.5}$. For VOC, we rely upon the dollar-per-ton value developed by NHTSA in the PRIA. Appendix L includes a description and summary tables of the benefits-per-ton values used in our calculations, along with a summary of the uncertainties and limitations that EPA identifies related to the development of these estimates and their application to specific regulations.

2. Results

Table 46 summarizes our estimates of the criteria pollutant damage reductions benefits due the alternative standards. Results for each of the alternative CAFE standards are relative to the augural standards baseline.

Table 46. Criteria Pollutant Emissions Reductions Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
NO_x Damage Reduction Benefits	$0.0	$0.0	$0.1	$0.1	$0.0	$0.0
VOC Damage Reduction Benefits	$0.0	$0.0	-$0.1	$0.0	-$0.1	-$0.1
$PM_{2.5}$ Damage Reduction Benefits	-$0.4	-$0.2	-$0.8	-$0.5	-$1.7	-$1.0
SO_2 Damage Reduction Benefits	-$2.0	-$1.2	-$3.4	-$2.0	-$6.1	-$3.6
Total	**-$2.4**	**-$1.4**	**-$4.2**	**-$2.5**	**-$8.0**	**-$4.7**

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. Values may not sum to totals due to rounding.

Source: NERA/Trinity calculations as explained in text.

[19] U.S. Environmental Protection Agency (EPA), 2018. "Technical Support Document Estimating the Benefit per Ton of Reducing $PM_{2.5}$ Precursors from 17 Sectors." February.

F. Summary of Social Benefits

Table 47 shows the social benefits of the three CAFE alternatives using 3 percent and 7 percent discount rates. The values include effects for model year vehicles up to MY 2029 based on impacts in calendar years from 2017 to 2050. Because the baseline ("no action" alternative) is the most stringent set of standards (augural standards), the values for social benefits for the three less-stringent CAFE standards are mostly negative, i.e., the values show the reductions in benefits from less-stringent standards. The exceptions are government fuel tax revenue (which is greater due to the larger fuel use from the less stringent CAFE standards) and some criteria pollutants (which have greater benefits because reductions in tailpipe emissions are larger than increases in upstream emissions).

Table 47. Social Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
Social Benefits Category	**3%**	**7%**	**3%**	**7%**	**3%**	**7%**
Valuation of Fuel Economy Benefits	-$28.0	-$19.1	-$49.0	-$33.3	-$87.2	-$59.5
Fuel Tax Revenue Benefits	$4.3	$2.6	$7.4	$4.4	$13.2	$8.0
Petroleum Market Externality Benefits	-$1.3	-$0.8	-$2.2	-$1.3	-$3.9	-$2.3
GHG Damage Reduction Benefits	-$1.6	-$0.2	-$2.9	-$0.3	-$7.1	-$0.7
NO_x Damage Reduction Benefits	$0.0	$0.0	$0.1	$0.1	$0.0	$0.0
VOC Damage Reduction Benefits	$0.0	$0.0	-$0.1	$0.0	-$0.1	-$0.1
$PM_{2.5}$ Damage Reduction Benefits	-$0.4	-$0.2	-$0.8	-$0.5	-$1.7	-$1.0
SO_2 Damage Reduction Benefits	-$2.0	-$1.2	-$3.4	-$2.0	-$6.1	-$3.6
Total Social Benefits	**-$29.0**	**-$18.9**	**-$50.9**	**-$32.9**	**-$93.0**	**-$59.3**

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. GHG damage reduction benefits values include benefits associated CO_2, as well as other GHG pollutants, which have been converted to CO_{2eq}. Values may not sum to totals due to rounding.

Source: NERA/Trinity calculations as explained in text.

VI. Net Benefits of Alternative CAFE Standards

This chapter provides information on the net benefits of the three alternative CAFE standards, i.e., benefits minus costs.

A. Net Benefits Using a 3 Percent Discount Rate

Table 48 summarizes the total social benefits, total social costs, and net benefits associated with each of the alternatives considered using a 3 percent discount rate.

Table 48. Net Benefits Relative to Augural Standards Baseline, 3% Discount Rate (billions of 2016$)

	Scenario 8	Scenario 5	Scenario 1
Social Costs			
Technology Costs	-68.8	-113.9	-170.7
Congestion Costs	-6.3	-10.6	-17.9
Noise Costs	-0.1	-0.2	-0.3
Fatal Crash Costs	-1.1	-1.3	-1.0
Non-Fatal Crash Costs	-1.5	-1.7	-1.3
Total Social Costs	**-77.7**	**-127.7**	**-191.2**
Social Benefits			
Valuation of Fuel Economy Benefits	-28.0	-49.0	-87.2
Fuel Tax Revenue Benefits	4.3	7.4	13.2
Petroleum Market Externality Benefits	-1.3	-2.2	-3.9
GHG Damage Reduction Benefits	-1.6	-2.9	-7.1
NO_x Damage Reduction Benefits	0.0	0.1	0.0
VOC Damage Reduction Benefits	0.0	-0.1	-0.1
$PM_{2.5}$ Damage Reduction Benefits	-0.4	-0.8	-1.7
SO_2 Damage Reduction Benefits	-2.0	-3.4	-6.1
Total Social Benefits	**-29.0**	**-50.9**	**-93.0**
Net Total Benefits	**48.7**	**76.8**	**98.2**

Note: Present values calculated as of January 1, 2017 using a 3 percent discount rate for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. GHG damage reduction benefits values include benefits associated CO_2, as well as other GHG pollutants, which have been converted to CO_{2eq}. Values may not sum to totals due to rounding.

Source: NERA/Trinity calculations as explained in text.

B. Net Benefits Using a 7 Percent Discount Rate

Table 49 provides estimates of the changes in social costs, changes in social benefits, and the net benefits using a 7 percent discount rate.

Table 49. Net Benefits Relative to Augural Standards Baseline, 7% Discount Rate (billions of 2016$)

	Scenario 8	Scenario 5	Scenario 1
Social Costs			
Technology Costs	-51.8	-85.4	-128.5
Congestion Costs	-3.9	-6.5	-10.9
Noise Costs	-0.1	-0.1	-0.2
Fatal Crash Costs	-0.9	-1.1	-1.0
Non-Fatal Crash Costs	-1.2	-1.4	-1.3
Total Social Costs	**-57.8**	**-94.5**	**-141.8**
Social Benefits			
Valuation of Fuel Economy Benefits	-19.1	-33.3	-59.5
Fuel Tax Revenue Benefits	2.6	4.4	8.0
Petroleum Market Externality Benefits	-0.8	-1.3	-2.3
GHG Damage Reduction Benefits	-0.2	-0.3	-0.7
NO_x Damage Reduction Benefits	0.0	0.1	0.0
VOC Damage Reduction Benefits	0.0	0.0	-0.1
$PM_{2.5}$ Damage Reduction Benefits	-0.2	-0.5	-1.0
SO_2 Damage Reduction Benefits	-1.2	-2.0	-3.6
Total Social Benefits	**-18.9**	**-32.9**	**-59.3**
Net Total Benefits	**38.9**	**61.6**	**82.6**

Note: Present values calculated as of January 1, 2017 using a 7 percent discount rate for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. GHG damage reduction benefits values include benefits associated CO_2, as well as other GHG pollutants, which have been converted to CO_{2eq}. Values may not sum to totals due to rounding.
Source: NERA/Trinity calculations as explained in text.

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Appendix A: CAFE Model and Application to This Project

This appendix provides an overview of the CAFE Model and describes its implementation by Trinity Consultants (Trinity). The CAFE Model discussed in this appendix refers to the July 2018 version developed by National Highway Traffic Safety Administration (NHTSA) to support the proposed Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Year 2021-2026 Passenger Cars and Light Trucks. Trinity similarly applied the 2018 CAFE Model (subsequently referred to as the CAFE Model) to estimate changes in vehicle, manufacturer and fleet compliance costs, technology penetrations and fuel economy levels needed to meet various alternative CAFE standards. A brief overview of the design/layout of the CAFE Model is presented first, followed by a discussion of the specific implementation of the CAFE Model for the analyses prepared in this study.

A. Overview of CAFE Model

The CAFE Model is designed to evaluate how vehicle manufacturers would comply with a given set of user-specified alternative fuel economy standards. From that evaluation, the model estimates penetrations of various technologies and the additional compliance costs for each manufacturer over each future model year. The baseline model (MY) year is MY 2016, and the CAFE Model evaluates compliance through MY 2032. In addition to compliance costs and technology penetrations, the CAFE Model also estimates changes in fuel consumption, vehicle emissions and various other social costs and benefits due to different CAFE alternatives. As noted in the body of this report, different models were used by NERA Economic Consulting (NERA) and Trinity to develop estimates of these other effects of CAFE alternatives, and thus we do not discuss these other aspects of the CAFE Model in this appendix.

Manufacturer compliance simulation within the CAFE Model starts with a user-specified vehicle model-level baseline fleet (with initial vehicle attributes and projected sales). The model then evaluates an array of possible compliance paths that incorporate additional vehicle technologies (beyond those within the baseline fleet) which provide various levels of fuel economy improvement. For each manufacturer fleet, the model evaluates plausible combinations of technology applications (i.e., the technology paths), seeking that path with the best cost-effectiveness, subject to several user-selected factors such as individual manufacturer willingness to pay, CAFE undercompliance penalties, and accumulation/carry forward of overcompliance credits from preceding model years.

Although the cost and effectiveness of each technology can be set by the user, we emphasize the Trinity made no changes to these inputs and used the reference values developed by NHTSA that were loaded into the CAFE Modeling system.

Once the CAFE Model has identified the optimal compliance path for each manufacturer (weighing difference technology combinations on different vehicles within the manufacturers passenger car and light truck fleets), it produces output reports on vehicle and manufacturer averaged technology application and costs.

Key elements of the CAFE Model's input files, user-selectable runtime configuration options, and output reports are summarized below.

1. Input Files

Inputs to the CAFE Model are organized into four user-configurable spreadsheet files summarized as follows:

1. *Market Data File*. This file contains detailed vehicle-level attribute data (size, footprint, baseline fuel economy and technology and model year sales) within a "Vehicles" worksheet. Detailed information on engine and transmission attributes and technology applicability is also defined in separate "Engines" and "Transmissions" worksheets, respectively. Finally, the "Manufacturers" worksheet specifies manufacturer-specific inputs that are germane to the compliance simulation such as individual manufacturer willingness to pay fines and baseline CAFE credit balances.
2. *Technologies File*. These estimates of the costs and availability of individual technologies are defined in this file. The CAFE Model evaluates compliance using a total of 66 individual vehicle, engine and transmission technologies. Cost information includes vehicle/engine size specific technology costs by model year as well as advanced hybrid/electric battery learned cost factors and stranded capital costs (where applicable). Cost synergies to address applicable engine technology combinations are also defined in this file.
3. *Parameters File*. These inputs are used to calculate various parameters used in the model are included in this file. The inputs include those used to develop information on the manufacturers' compliance plans as well as others that are used in subsequent calculations of social costs and social benefits.
4. *Scenarios File*. Fuel economy and CO_2 standards scenarios defining the coverage, structure and year-to-year stringency are specified in the Scenarios file. Note that in keeping with the main report, we describe different standards as alternative CAFE standards rather than scenarios.

2. Runtime Settings

Various run configuration options can be enabled/disabled or specified within the CAFE Model's "Runtime Settings" panel within the user interface. The ones relevant for our analyses are summarized below[20]:

- *Compliance Program to Enforce*. This specifies the compliance program the model should enforce when evaluating a manufacturer's compliance state. If "CAFE" option is

[20] "Draft CAFE Model Documentation," U.S. Department of Transportation, National Highway Traffic Safety Administration, July 2018, ftp://ftp.nhtsa.dot.gov/CAFE/2021-2026_CAFE_NPRM/CAFE_Model/CAFE_Model/CAFE_Model_Documentation_NPRM_2018.pdf

selected, the model will seek compliance with NHTSA's CAFE standards. If "CO-2" option is selected, the system will seek compliance with EPA's CO_2 standards.

- *Fuel Price Estimates*. This specifies whether to use the low, average, or high fuel price estimates from the parameters input file. By default, average fuel price estimates are used.

- *Begin Technology Application Starting In*. This specifies the starting model year when the system will begin evaluating technologies for application on vehicles. Prior to this year, the system will only determine manufacturers' compliance levels, generate available credits and fines owed, and use expiring credits (if credit trading option is enabled) to offset compliance shortfalls as needed. Any non-expiring banked credits available prior to start of the analysis (which are specified as input for each manufacturer) will not be used for model years prior to this starting year.

- *Allow Credit Trading*. This specifies whether the model should allow manufacturers to transfer credits between passenger car and light truck fleets and to carry-forward credits forward from previous model years into the analysis year. (The model currently does not simulate either credit "carry-back" or trading between different manufacturers.)

- *Last Credit Trading Year*. This specifies the last model year during which credits may be transferred or carried forward. A value of 2020 indicates that manufacturers may transfer and carry forward credits through and including model year 2020.

- *Perform Fleet Analysis Calculations*. This specifies whether the model should perform fleet analysis calculations, evaluating modeling effects for historic and forecast model years (before the first compliance model year as well as after the last compliance model year).

3. Output Results

Finally, the CAFE Model's outputs include a series of "report" files in CSV format. The following are the reports relevant for our study.

- *Compliance Report*. This provides manufacturer-level and industry-wide summary of compliance model results for each model year and scenario analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.

- *Technology Utilization Report*. This provides manufacturer-level and industry-wide technology application and penetration rates for each technology, model year, and scenario analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.

- *Vehicles Report*. This provides a detailed view of the final state of each vehicle examined by the model, for each model year and CAFE alternative analyzed.

B. Trinity Implementation of CAFE Model

Trinity considered four CAFE standards—including the augural standards and three alternatives—as noted in the main report. Table A-1 summarizes these four CAFE standard alternatives.

Table A-1. CAFE Alternatives Evaluated in This Study

Alternative	Change in stringency
Baseline/ No-Action ("Augural")	MY 2021 standards remain in place; MYs 2022-2025 augural CAFE standards are finalized; MY 2026 standards are set at MY 2025 levels
8	Existing standards through MY 2021, then 2%/year increases for passenger cars and 3%/year increases for light trucks, for MYs 2022-2026
5	Existing standards through MY 2021, then 1%/year increases for passenger cars and 2%/year increases for light trucks, for MYs 2022-2026
1	Existing standards through MY 2020, then 0%/year increases for both passenger cars and light trucks, for MYs 2021-2026

Note: There are no changes in A/C Efficiency or off-cycle provisions.

1. CAFE Model Input Files and Runtime Settings

The CAFE Model input files and runtime settings were set to those used by NHTSA to support the "Unconstrained" analysis[21] referred to in the Draft Environmental Impact Analysis (DEIS). Table A-2 presents a detailed listing of the CAFE Model input files and runtime settings used in the analysis.

[21] As described in Section 2.3.2 of the DEIS, NHTSA's CAFE Model results presented in the NPRM differ slightly from those presented in the DEIS. EPCA and EISA require that the Secretary determine the maximum feasible levels of CAFE standards in a manner that sets aside the potential use of CAFE credits or application of alternative fuels toward compliance with new standards. NEPA, however, does not impose such constraints on analysis; instead, its purpose is to ensure that "public officials make decisions with an understanding of environmental consequences." The DEIS therefore presents results of an "unconstrained" analysis that considers manufacturers' potential use of CAFE credits and application of alternative fuels in order to disclose and allow consideration of the real-world environmental consequences of the Proposed Action and alternatives.

Table A-2. CAFE Model Configurations Used in This Study

Category	Primary Option	Matches NHTSA Unconstrained?
Input File Options		
Market Data (– Payback Period)	60 months	No
Market Data (Manufacturers– Fines Preference)	Defaults by manufacturer	Yes
Technologies – BEV200s and FCV availability	Used "BEV_FCV" input file	Yes
Parameters (Safety Values) – Weight-Related Fatalities	0%	Yes
Scenarios (Fine Rate)	$5.50 in MY 2016, 1% Discount Rate	Yes
Runtime Settings		
StartYear	2017	Yes
ComplianceProgram	CAFE	Yes
MultiYearModeling	True	Yes
AllowCreditTrading	True	Yes
LastCreditTradingYear	2032	Yes
NoFines	False	Yes
Backfill	True	Yes
FleetAnalysis	True	Yes
DynamicFleetShare	False	No
DynamicScrappage	False	No
ConsumerBenefitsScale	Turned off	Yes
FuelPriceEstimates	Average	Yes
CO2Estimates	Average	Yes

Note: There are no changes in A/C Efficiency or off-cycle provisions.

Apart from three settings that reflect the use of substitute results from the New Vehicle Market Model and the Scrappage Model—as discussed in Appendices B and C—the CAFE Model input files were the same as those used by NHTSA in their Unconstrained DEIS analysis. (This included use of NHTSA's "2018_NPRM_technologies_with_BEV_and_FCV_ref.xlsx" Technologies file input which enables application of alternative technologies/fuels consistent with the Unconstrained case.)

The payback period is a required setting in the CAFE Model. A value of 60-months was used for this setting in the Trinity implementation of the CAFE Model—replacing the 30-month value used in the PRIA—for consistency with the results of the New Vehicle Market Model (which provides an estimate of the value new vehicle purchasers place on fuel economy improvements).

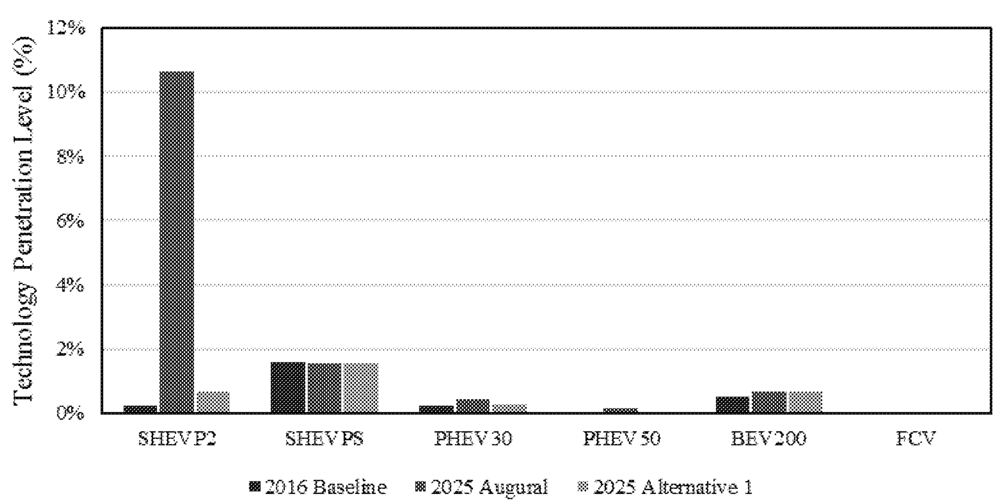
2. Advanced Powertrain Projections in CAFE Model

As noted earlier, the CAFE Model evaluates over 60 individual technologies within a series of technology pathways to identify the optimum pathway and the compliance costs and fuel economy changes associated with that pathway. These calculations are performed for each manufacturer's unique fleet. This subsection summarizes CAFE Model projections for "advanced powertrain" technologies, which refers to strong hybrids, plug-in electric hybrids, battery electric vehicles and fuel cell vehicles. This definition encompasses six individual technologies within the CAFE Model as follows:

- SHEVP2 – P2 parallel strong hybrid;
- SHEVPS – Power split strong hybrid;
- PHEV30 – Plug-in hybrid electric vehicle, 30-mile battery range;
- PHEV50 – Plug-in hybrid electric vehicle, 30-mile battery range;
- BEV200 – 200-mile battery electric vehicle; and
- FCV – fuel cell vehicle.

Figure A-1 shows the CAFE Model projected advanced powertrain technology levels in model year 2025 under both the augural standards and the Alternative 1 standards and compares these projected levels to those that currently exist in MY 2016 (the baseline year for the CAFE Model). The technology penetration levels shown in Figure A-1 are sales-weighted averages across all manufacturers' light-duty vehicle fleets.

Figure A-1. CAFE Model Advanced Powertrain Technology Penetration Levels



As shown in Figure A-1, with the exception of P2 strong hybrids (which are projected to increase from 0.23% in the 2016 baseline to 10.66% by MY 2025 under compliance with the augural standards), the CAFE Model projects little change in other advanced powertrain fleet penetration levels under either the augural standards or the Alternative 1 standards by 2025.

Under the augural standards, the CAFE Model projects nominally higher PHEV levels in 2025 than 2016 (for example, 0.46% vs. 0.24% respectively for PHEV30). The CAFE Model also projects small increases in penetration levels of pure electric vehicles (BEV200) under either alternative: 0.67% under the augural standards and 0.66% under Alternative 1 in 2025 relative to the current 2016 baseline level of 0.52%.

These modest changes in projected advanced powertrain technology levels are the result of the CAFE Model's technology path optimization logic, which seeks to calculate the most cost-effective compliance path for each manufacturer's vehicle fleets.

C. References

National Highway Traffic and Safety Administration (NHTSA), 2018. "Draft CAFE Model Documentation." July.

National Highway Traffic Safety Administration (NHTSA), 2018. "Draft Environmental Impact Statement: The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Year 2021-2026 Passenger Cars and Light Trucks." *Docket No. NHTSA-2017-0069*. July.

Appendix B: New Vehicle Market Model

This appendix provides information on the New Vehicle Market Model, the model developed by NERA to model the market for new motor vehicles. The New Vehicle Market Model is used in this study to develop estimates of the value that consumers place on fuel economy improvements and, in conjunction with the results of the CAFE Model for compliance costs, to develop projections of new motor vehicle sales under the three CAFE alternatives.

A. Conceptual Approach: Nested Logit Model

Logit discrete choice analysis provides a method for predicting consumer choices, and therefore demand, based on previously observed consumer behavior and other assumptions about demand (see, e.g., Ben-Akiva and Lerman 1985). The most basic logit model, also referred to as the simple logit, groups all product alternatives together and therefore allows only limited variation in own-price and cross-price elasticity between different alternatives. This limitation is often referred to as the "Independence of Irrelevant Alternatives" ("IIA") property. The nested logit model builds on this simple framework, while allowing for a much richer pattern of cross-substitution between different alternatives through the nesting structure.

1. Basic Framework

In our New Vehicle Market Model, consumers choose among a set of vehicle models, and may also choose not to purchase a vehicle at all. For alternative (vehicle model) *i*, the utility that a given consumer obtains from choosing that alternative can be written as a function of an alternative-specific parameter and the price for the alternative:

$$\boldsymbol{U_i = \alpha_i - \beta P_i + \varepsilon_i} \qquad \textbf{(1)}$$

Alternative "0" is defined as the no-purchase alternative, and the remaining alternatives represent decisions to purchase individual vehicle models. The parameter α_i measures the attractiveness of good *i* to consumers. We assume that the price for the outside good is zero. P_i is the price of alternative *i*, and β is a positive coefficient. The random error terms ε_i are assumed to be distributed as a multivariate generalization of the standard extreme value distribution. It is this assumption about the distribution of the error terms that gives rise to the logit model.

The potential purchaser is assumed to choose the alternative that yields the highest utility, taking into account both the deterministic and random components of utility. Given the logit demand assumptions, we determine the expected market share for each vehicle model. Conditional upon the consumer's decision to purchase a vehicle model within a vehicle group (or "nest") *A* (as described below), the expected share for vehicle model *i* can be written as:

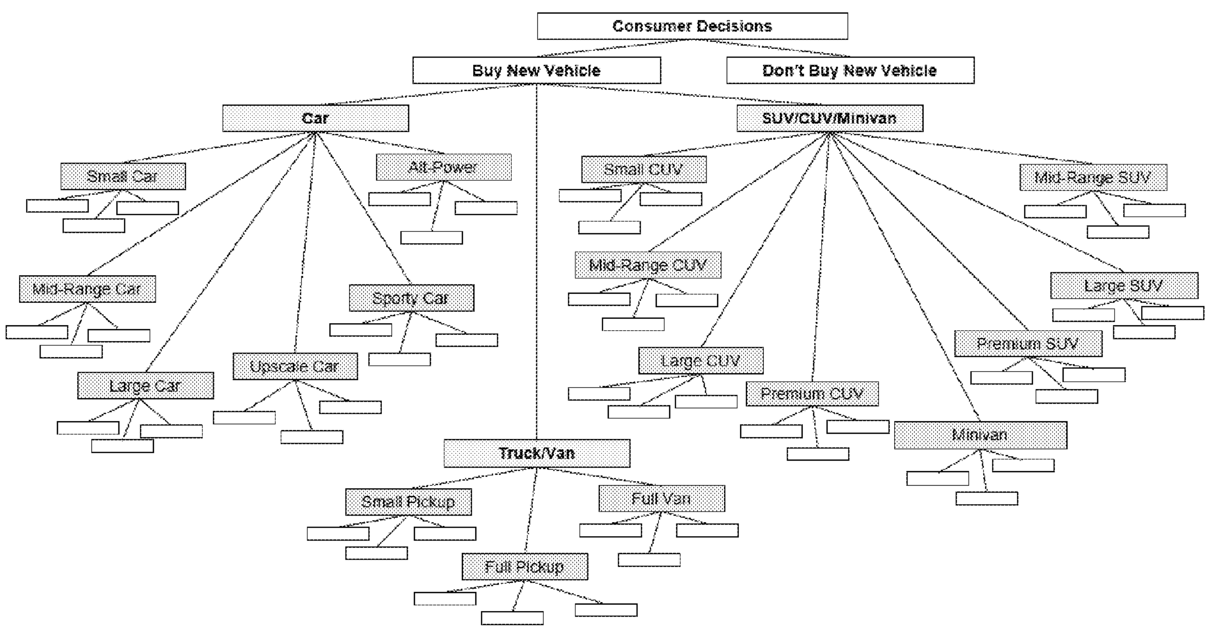
$$\boldsymbol{s_{i|A} = \frac{\exp((\alpha_i - \beta P_i)/\lambda_A)}{\sum_{j\in A} \exp((\alpha_j - \beta P_j)/\lambda_A)}} \qquad \textbf{(2)}$$

where λ_A is the "nesting parameter" for the appropriate vehicle group, or "nest" (as described below).

2. Nesting Assumptions

Our logit model assumes the nesting structure shown in Figure B-1. We divide the choice problem first into the decision of whether to buy a new vehicle. Conditional upon the choice to purchase a new vehicle, consumers choose the vehicle type—in this case, passenger cars; pickup trucks or full-size vans; and SUVs, CUVs, or minivans. Conditional on the choice of vehicle type, consumers choose the vehicle class—for example, small cars or mid-range cars (among others) in the passenger-car group. Conditional on the vehicle class (e.g., mid-range car, small SUV, etc.), consumers choose one of the individual vehicle models available. The bottom level of the nesting structure includes 296 vehicle models from which consumers may choose.

Figure B-1. Nesting Structure for New Vehicle Market Model



The new vehicle market model allows the utility that consumers derive from the purchase of different models to depend on the vehicle category and class via the nesting parameters (λ_A), which take values between zero and one[22]. One nesting parameter applies to the purchase decision (buy or do not buy a vehicle); another nesting parameter applies to the choice of vehicle type; and a third applies to the choice of vehicle classes. The nesting parameters for the purchase decision must be at least as large as the nesting parameter for all vehicle nests contained within the "parent" nest. The nesting structure implies that vehicles within one group are closer substitutes for each other than they are for vehicles in different groups. The cross-price

[22] The nesting parameters are sometimes called "inclusive value coefficients."

elasticities between vehicles within the same group are therefore higher than the cross-price elasticities for vehicles in different groups.

As noted above, one advantage of the nested logit model over the simple logit model is that it provides for a richer pattern of own- and cross-price elasticities. In the nested logit model, the IIA property need not hold across groups. That is, the ratio of the share for a particular car model in one bottom-level nest to the share of a vehicle in a different bottom-level nest, for example, depends not only on the characteristics of those two vehicle models, but also on the substitution patterns implied by the nesting structure and nesting parameters. The nesting parameters therefore enrich the simple logit model. If all nesting parameters equal one, then the nested logit model becomes a simple logit model.

The inclusive value term I_A for the bottom-level group A (the vehicle class) is defined as:

$$\boldsymbol{I_A = \ln\left[\sum_{j\in A} \exp((\alpha_j - \beta P_j)/\lambda_A)\right]} \tag{3}$$

The inclusive value term I_X for the top-level group X (the vehicle type) is defined as:

$$\boldsymbol{I_X = \ln\left[\sum_{A\in X} \exp(I_A \lambda_A)/\lambda_X)\right]} \tag{4}$$

Finally, the inclusive value term for the purchase alternative is defined as:

$$\boldsymbol{I_X = \ln\left[\sum_{X} \exp(I_X \lambda_X)/\lambda_{buy})\right]} \tag{5}$$

The share of the bottom-level group A in purchases within the top-level group X to which A belongs can be written as:

$$\boldsymbol{s_{A|X} = \frac{\exp(I_A \lambda_A)/\lambda_X)}{\sum_{B\in X} \exp(I_B \lambda_B)/\lambda_B)}} \tag{6}$$

The share of top-level group X in total purchases can be written as:

$$\boldsymbol{s_{X|buy} = \frac{\exp(I_X \lambda_X)/\lambda_X)}{\sum_{Y} \exp(I_Y \lambda_Y)/\lambda_Y)}} \tag{7}$$

The logit framework gives an expression for the share of potential buyers who choose to purchase a vehicle:

$$\boldsymbol{s_{buy} = \frac{\exp(I_{buy} \lambda_{buy})/\lambda_{buy})}{\exp\left(I_{buy} \lambda_{buy}\right) + \exp(\alpha_0)}} \tag{8}$$

where α_0 is the value derived by the consumer from a no-purchase decision.

The unconditional share for alternative i can be written as the product of the purchase probability and the conditional probabilities:

$$s_i = s_{buy} s_{X_i|buy} s_{A_i|X_i} s_{i|A_i} \tag{9}$$

where A_i is the bottom-level group to which i belongs and X_i is the top-level group to which A_i belongs.

B. Solving for Parameters

As described above, the nested logit choice framework provides a method to estimate consumer demand for differentiated products, using as data the prices and parameters that measure the relative attractiveness of each product. Using the logit framework, we solve simultaneously for the beta parameters and "alternative-specific" parameters that are consistent with the observed market shares and prices. If two products in the same group have the same price but different market shares, then the one with the higher share must be more attractive to consumers. Similarly, if two products in the same group have the same market share but different prices, then the one with the higher price must be more attractive to consumers, since consumers are observed to pay a premium for it.

We use the logit framework to calibrate alternative-specific parameters for each vehicle model. We make assumptions concerning the nesting parameters, the aggregate price elasticity of demand, and the price elasticity of demand for one specific normalized alternative. Given the structure of our nested logit model, these assumptions, the observed prices, and the observed market shares are sufficient to derive estimates of the alternative-specific parameters (including those for the outside good).

C. Estimating Consumer Valuation of Vehicle Attributes

Once the alternative-specific parameters implied by the observed vehicle shares and prices are calculated, we estimate the extent to which consumers value each vehicle attribute through a "second-stage" regression for the alternative-specific parameters. We consider the effects of specific vehicle attributes such as horsepower/weight (a common measure of acceleration), size (length multiplied by width), and the cost of fuel per mile driven ($/mile, which is the product of gallons-per-mile and the fuel price).

We assume each vehicle's alternative-specific parameter depends upon the vehicle's model and attributes according to the following model:

$$\alpha = \varphi X + \delta_{year} D_{year} + \delta_{season} D_{season} + \phi_{model} D_{model} + \varepsilon \tag{10}$$

where

α is the alternative-specific coefficient at time t,

X are vehicle characteristics at time t,

D_{year} are dummy variables corresponding to vehicle model years,

D_{season} are dummy variables corresponding to seasons (calendar quarters),

D_{model} are dummy variables corresponding to the vehicle model, and

ε is an error term capturing unobserved characteristics

Our model uses quarterly data on sales and prices combined with information on vehicle characteristics for each model year. Thus, the t subscript indexes quarters. We estimated this equation using ordinary least squares (OLS) and tested for the presence of autocorrelation in the error terms. We found significant autocorrelation, as evidenced by a statistically significant coefficient on the lagged residuals in a regression of the residuals from the OLS estimation on the residuals lagged one period. To correct for autocorrelation in the error terms, we re-estimated the equation using feasible generalized least-squares (FGLS) with first-order autoregressive disturbances. In this model, the error terms are related to their lagged values by a parameter ρ between 0 and 1.

Table B-1 reports the result of this regression. The coefficients on size and horsepower/weight are positive and significant, as expected. The model-year, seasonal, and vehicle-model sets of categorical dummy variables are each jointly significant. The coefficient on $/mile is negative, as expected (the higher the $/mile, the higher the operating cost, and the less a consumer would value the vehicle, controlling for other factors) and highly significant. The estimated coefficient provides a means of valuing improvements in miles per gallon (decreases in $/mile) that can be used to estimate the benefits to new vehicle purchasers of changes in fuel economy.

Table B-1. Estimation Results for Alternative-Specific Parameter Model

Independent variable	coeff.	t-statistic	std. error	p > |t|
$/mile	-2.559	-8.211	0.312	0.0000
hp/weight	2.158	3.001	0.719	0.0027
size	0.649	4.546	0.143	0.0000
constant	-2.112	-9.726	0.217	0.0000
categorical dummies	**significance test**	**$\chi2$ -statistic**		**p > |$\chi2$|**
Model Year	$\chi2$	474.031		0.0000
Season	$\chi2$	383.266		0.0000
Vehicle Model	$\chi2$	6684.904		0.0000
Autocorrelation parameter	**estimated value**			
ρ	0.7846			
σ	0.1257			

Note: The weight variable is curb weight in units of pounds. The size variable is the product of vehicle length and width (both expressed in hundreds of inches).
Source: NERA calculations as explained in text.

The dollar value of a unit improvement in a vehicle attribute can be inferred from this model by taking the ratio of the coefficient on that attribute to the price coefficient (the β term in Equation (1)) multiplied by -1. We express price in units of $20,000. The average β parameter estimate across all quarters in the New Vehicle Market Model is 0.737. Thus, the dollar value Willingness-to-Pay (WTP) for a $0.01/mile reduction in operating costs can be calculated as:

$$WTP_{\$0.01/mile} = \frac{-2.559}{-0.737} * 200 = \$694 \tag{11}$$

That is, improving fuel economy by an amount equivalent to lowering the cost per mile by $0.01 is worth an extra $694 in the price of a new vehicle. For example, suppose the MPG of an average vehicle increases from 30 MPG to 35 MPG at a gasoline price of $2.50. At 30 MPG, vehicle fuel costs $2.50/30 = $0.0833 per mile. At 35 MPG, the cost is $2.50/35 = $0.0714 per mile, for a reduction of $0.0833 - $0.0714 = $0.0119 per mile, or 1.119 cents per mile. This reduction in fuel cost per mile should be worth about 1.119 * $694 = $777 based upon the information implied in vehicle purchasers' behavior.

D. Specific Implementation Parameters and Data

a. Vehicle Sales

We use quarterly vehicle sales data from J.D. Power and Associates to determine the market share for each vehicle model, aggregated across trim levels, for MYs 2013-2017. We match model year vehicle characteristics to sales from October of the previous calendar year to September of the same calendar year to reflect as accurately as possible the timing of new model availability. For example, vehicle characteristics for MY 2014 vehicles are paired with sales data for the fourth quarter of 2013 through the third quarter of 2014. If a vehicle model sold less than

200 units in a given quarter, we eliminated it from the data set for that quarter. We also eliminated observations where models sold substantially more or fewer units than the following or previous period to avoid biasing our estimates of attributes valuation due to the introduction or discontinuation of vehicle models.

b. Vehicle Prices

We use quarterly data on transaction prices for each model from J.D. Power and Associates for the United States. The transaction prices are sales weighted across trims and reflect the different prices charged for different trim levels.

c. Vehicle Fuel Economy Data and Other Vehicle Characteristics

We rely on vehicle characteristic data that we acquired from Ward's Automotive for each model in our sample. The data we acquired from Ward's included fuel economy information based on the fuel economy metrics maintained by EPA as reported on fueleconomy.gov. While EPA maintains several measures of fuel economy, for this analysis we use the two-cycle definition of fuel economy (i.e., EPA unadjusted) for consistency with the metric NHTSA uses to set CAFE Standards. We also rely on data from Ward's for information on other vehicle attributes, including curb or test weight, horsepower, length, and width.

Note that the Ward's dataset is organized at the trim level. We match the Ward's characteristics for the trim level with the highest sales (based on the JDPA sales data) to the JDPA sales volume and transaction price data. For certain vehicle trim levels in the Wards data, there are multiple versions within a trim (e.g., differing powertrain and transmission options). In these instances, we average across the various options within a certain trim level.

d. Categorization of Vehicle Models into Nests

We use vehicle categorizations from the 2013-2016 Automotive News Market Data Book to define the vehicle nesting structure depicted in Figure B-1. Where the appropriate category for a particular model could not be determined, including models new to 2017 for which Automotive News did not publish categorizations, we used Ward's categorizations and/or the categorization of comparable vehicles.

The Automotive News Market Data Books include hybrids and electric vehicles in an "Alt. Power" category within the cars segment of the market. Following this, we place all alternative power vehicles in an "Alt. Power" nest within the cars nest. As a sensitivity check, we explored alternative nesting strategies for these vehicles, including assigning alternative power vehicles to the same nest as their criteria power counterpart as available (e.g., the RAV4 Hybrid would be in the same nest as the RAV4) and having alternative power vehicles as an additional upper level nest. None of these alternative strategies yielded significantly different results.

e. Price Elasticity

Consistent with various literature sources, we assume an aggregate elasticity for the new vehicle market of -1.0[23]. We set the own-price elasticity of the "normalized" vehicle model (whose alternative-specific parameter is normalized to zero) to be -4.0, which is consistent with various other literature estimates of individual model own-price elasticities.[24]

The nesting parameters for nested logit models represent the similarity between choices for vehicles falling within the same "nest". The nesting parameters influence the relative substitutability within each nest, and also between different nests. Nesting parameters may take any value between zero and one, with lower values indicating greater similarity between the alternatives within the respective nest. For the "Buy" nest we use a nesting parameter equal to 0.9, for vehicle types we use a nesting parameter equal to 0.6 and for vehicle classes we use a nesting parameter equal to 0.3.

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[23] See, for example, Gruenspecht (2000).

[24] See, for example, Berry, Levinsohn, and Pakes (1995).

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Appendix C: Scrappage Model

This appendix provides information on the Scrappage Model developed by NERA for use in this study.

A. Vehicle Prices and Scrappage Behavior

The idea that economic as well as technical considerations can influence the life spans of durable capital goods such as motor vehicles has long been recognized. Specifically, the link between a vehicle's market value and its service lifetime was first explicitly recognized more than three decades ago. This logic is straightforward: a vehicle is retired from service (or scrapped) when it is no longer worth the expense of keeping it in working condition. That is, when the difference between the vehicle's resale price (in working condition) and the cost of keeping it in this condition is less than its scrap value, the vehicle is scrapped.

Building on this basic insight, early research by Walker (1968) and Parks (1977) investigated the influence of a vehicle's market value, as well as characteristics such as its age, on the vehicle owner's decision to retire the vehicle from service rather than maintain it in working condition. Both authors present statistical evidence of the influence of vehicle prices on the scrappage rates of used vehicles of different model year vintages and ages, demonstrating that variation in automobile prices exerts a detectable influence on scrappage rates of used cars. Berkovec (1985) later incorporated the framework developed in this earlier research in a model encompassing new automobile production and sales activity, vehicle pricing behavior, and scrappage of used autos.

Also drawing on previous results, Gruenspecht (1982) recognized that the connection between new and used vehicle prices—whereby rising prices for new models exert an upward "pull" on resale prices for used vehicles—meant that changes in prices for new automobiles could influence scrappage decisions by older cars' owners. As a result, he hypothesized, emissions regulations that raised production costs and sales prices of *new* vehicles might retard the scrappage and replacement of older models sufficiently to offset the reduction in criteria emissions from introducing cleaner new models into the vehicle fleet. Gruenspecht's research produced evidence that the increase in new car prices resulting from manufacturers' compliance with the 1980-81 federal emissions standards could be sufficient to have this effect.

Following Gruenspecht's early efforts, several more recent studies have further investigated the determinants of vehicle scrappage, often focusing on the role that fuel prices play in shaping the relative value, and therefore the price, of used vehicles (Li, Timmins, & von Haefen, 2009; Sallee, West, & Fan, 2010; Allcott & Wozny, 2014; Busse, Knittel & Zettelmeyere, 2013; Jacobsen and van Benthem, 2015).

B. Model Used in this Study

The vehicle scrappage model used here is based on well-established economic theory and empirical evidence on the response of owners' decisions about retiring (or "scrapping") used vehicles to changes in economic factors. The model estimates a relationship between new car and truck prices and scrappage or retirement rates for cars and trucks of different model year vintages at each age during their lifetimes.

This study estimates a "reduced-form" scrappage model using aggregate scrappage rates by type (car or truck) for the individual vehicle model years making up the U.S. passenger vehicle fleet over the 2002-2016 period (rather than the scrappage rates for individual vehicle models originally employed by Gruenspecht). Updating results from earlier scrappage studies that analyzed the scrappage response to changes in new vehicle prices is necessitated by increases in the expected lifetimes and average ages of passenger vehicles that have occurred over time. We also update the methodology to incorporate techniques of recent studies to better isolate the relationship of new vehicle prices on scrappage behavior.

1. Basic Theory of the Model

A vehicle's owner will retire the vehicle from service and sell it for its scrap value if its value in working condition exceeds its scrap value by less than the expected cost of repairs necessary to maintain it in working condition. Since the expected cost of these repairs depends on how long a vehicle has been in service as well as on the materials and manufacturing technology employed when it was produced, the probability that it will be scrapped is likely to depend on both its original model year and its age. To some extent, a vehicle's age may simply be a surrogate measure of its accumulated usage, although its age per se may also affect its sale value in working condition and thus the likelihood that it will be retired.

At the aggregate or fleet-wide level, the scrappage rate among a "cohort" of vehicles in service (measured by the proportion of those in service at the beginning of a year that are retired or scrapped before the year ends) will thus depend on both their model year and their age during that year. The scrappage rate will also reflect other factors that affect the value of repairing and operating a used vehicle as opposed to scrapping the vehicle. Most notably, because prices for new vehicles are in turn an important influence on prices for used vehicles of different ages, scrappage rates are likely to be affected by changes in new vehicle prices and the myriad factors that determine them (including manufactures' costs for complying with government regulations).

Finally, scrappage rates for all model years in service are also likely to be affected, although not necessarily uniformly, by changes in other economic variables such as employment or personal incomes. This occurs because keeping used vehicles in service longer provides a temporary mechanism for accommodating increases in total demand for motor vehicle travel that result from changes in economy-wide conditions. Extending the service lifetime of a used vehicle in order to accommodate increased travel demand is accomplished by deferring its retirement beyond the age at which it would otherwise have occurred, a response that reduces the aggregate scrappage rate for vehicles of various ages.

2. Model Variables and Data Sources

The data used to develop this model of these empirical relationships include scrappage rates calculated from U.S. annual vehicle registration data for the years 2002 through 2018. We rely on registrations data for passenger cars and light trucks provided from *IHS Markit* that reflects the number of registered vehicles on the road (i.e., vehicles in operation) as of January 1st of each calendar year in our sample. For each calendar year from 2002-2018, we use this registration data to calculate scrappage rates for vehicles of ages 4 through 19 years, and an overall scrappage rate for vehicles that are 20 years and older. The scrappage rate is measured as the decrease in registered vehicles over the year divided by the number of registered vehicles at the beginning of the year. Note that we calculate separate scrappage rates for passenger cars and light trucks. While the specific types of vehicles included in these registration data - and thus in the scrappage rates used to develop this model - vary over the extended period covered by this study, for most of those periods they closely match those encompassed by the federal government's GHG standards and CAFE standards.

Prices for new cars and trucks are based upon new car and new truck prices indices from the Bureau of Labor Statistics (BLS 2018). These indices make quality adjustments to the new vehicle prices—this would be a limitation for assessing the sensitivity of scrappage to changes in price alone, but in the context of changing prices and fuel economy simultaneously (as under alternative CAFE standards), it is the change in quality adjusted price that is more relevant. Consistent with this choice of price variable in the scrappage model, we use quality adjusted prices in implementing the results of the scrappage model within the Fleet Population Model described in Appendix D. We scale the indices to 2016 dollars using the average expenditure on a new cars and new trucks in 2016 as reported by the Bureau of Economic Analysis (BEA 2018).

3. Model Form and Estimation

The specific mathematical form of the scrappage model employs the measure

$$\ln\left(\frac{s}{1-s}\right) \qquad \textbf{(12)}$$

as its dependent variable, where s is the aggregate scrappage rate for vehicles of an individual model year at a specific age and of a specific type (car or light truck), and ln(.) denotes the natural logarithm. This transformation of the scrappage rate, sometimes called the "logit" of the scrappage rate, converts a measure bounded by the values zero and one—and in practice varying over a much narrower range—to one spanning a wider range of values. Using the transformed value of the scrappage rate as the model's dependent variable allows the estimated coefficients to exhibit desirable statistical properties.

The estimation equation regresses this dependent variable against the variable of interest, new prices by vehicle type, as well as a rich set of fixed effects similar to those employed in the Jacobsen-van Benthem study (2015). Specifically, we use the following regression equation for scrappage rates s by vehicle type t, age a, and calendar year y.

$$\ln\left(\frac{s}{1-s}\right)_{t,a,y} = \boldsymbol{\beta_{y,t}YearType + \beta_{a,t}YearAge + \gamma NewPrice_{t,y} + \varepsilon} \qquad \textbf{(13)}$$

For example, the scrappage of model year 1995 trucks in calendar year 2005 would be determined by the price of a new truck in 2005 along with a fixed effect for trucks of all ages in 2005 and a fixed effect for all age 10 vehicles in 2005. The rich set of fixed effects serve to absorb the complicating effects of the various macroeconomic factors that exert differential effects on scrappage behavior of different types and ages of vehicles.

Note that the results of the regression model using the logit transformation can be transformed back into an estimated relationship between the scrappage rate itself and the explanatory variables. Specifically, the elasticity of scrappage with respect to new vehicle prices for a vehicle of age *a* and type *t* will be

$$\varepsilon_{a,t} = \gamma * NewPrice_t * (1 - s_{a,t}) \tag{14}$$

where is the coefficient on new price from the regression and *s* is the scrappage rate.

4. Statistical Results

The resulting model performs well in explaining variation among scrappage rates across the wide range of model years and extended historical period spanned by the underlying data. Table C-1 presents the statistical coefficient estimates and other results of the estimated model in detail.

Table C-1. Scrappage Regression Results

Dependant Variable	ln[s/(1-s)]		**R-Sqaured**	0.9997
Sample Period	2002-2016			
Number of Observations	510		**Root MSE**	0.0643
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**p > |t|**
New Vehicle Price	-0.065	0.002	-29.791	0.0000
Categorical Dummies	**# of dummies**		**F-statistic**	**p > |F|**
Year*Type	30		360.726	0.0000
Year*Age	254		7085.075	0.0000

Source: NERA calculations as explained in text.

The coefficient on new vehicle price has the expected direction and is very highly significant (t = -29.791). Using the equation above, we translate this coefficient into elasticities of scrappage with respect to new vehicle price. These elasticities are shown in Table C-2.

Table C-2. Scrappage Elasticities with Respect to New Vehicle Price by Vehicle Age

	Age-Specific Scrappage Rates		Elasticity of Scrappage with Respect to New Vehicle Price	
	Cars	Light Trucks	Cars	Light Trucks
Age 4	0.029	0.011	-1.587	-2.336
Age 5	0.032	0.014	-1.581	-2.329
Age 6	0.035	0.015	-1.576	-2.327
Age 7	0.042	0.019	-1.565	-2.317
Age 8	0.048	0.026	-1.555	-2.301
Age 9	0.055	0.030	-1.545	-2.290
Age 10	0.063	0.037	-1.531	-2.274
Age 11	0.075	0.045	-1.512	-2.255
Age 12	0.087	0.050	-1.493	-2.243
Age 13	0.100	0.059	-1.471	-2.223
Age 14	0.117	0.073	-1.443	-2.190
Age 15	0.137	0.081	-1.410	-2.170
Age 16	0.149	0.093	-1.391	-2.141
Age 17	0.168	0.099	-1.360	-2.128
Age 18	0.173	0.105	-1.352	-2.114
Age 19	0.189	0.101	-1.326	-2.124
Age 20+	0.200	0.114	-1.307	-2.091

Source: NERA calculations as explained in text.

5. Using the Scrappage Model to Estimate Fleet Population Effects

We use the estimates of the effects of changes in prices (adjusted for utility as described in Appendix B) due to the alternative standards in conjunction with the age-type-specific effects of new vehicle prices on scrappage rates produced by this model to simulate future changes in the age distribution of the vehicles in the national fleet. Specifically, we calculate the changes in scrappage rates for vehicles of each age from four to 20+ predicted by the model's elasticity estimates to result from the specified increases in the average sales price of new cars and light trucks. We assume that scrappage rates for vehicles three years old and less would not change in response to higher prices for new vehicles.

These overall age-specific changes in scrappage rates due to each of the scenarios are then applied to scrappage rates for vehicles of each age in the baseline projected vehicle populations to produce estimates of the changes in vehicle populations due to the CAFE standards in the studied regulatory scenarios.

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Appendix D: Fleet Population Model

The fleet population model combines the results of the New Vehicle Market Model and the Scrappage Model to determine the impacts of the alternative standards on the overall passenger car and light truck fleet for MY 2021-2029.

A. Baseline Scenario

We develop a detailed baseline forecast of the U.S. vehicle fleet population based upon the vehicle population projections in EPA's MOVES vehicle emission inventory model, as implemented by Trinity. The MOVES model includes projections of the vehicle fleet organized by vehicle type and vintage for each of the relevant years. These fleet projections are based on information from the U.S. Energy Information Administration's (EIA) Annual Energy Outlook (AEO) 2014.[25] The AEO2014 projections reference case assumes the augural standards remain in place. All fleet population effects, described in the next section, are modeled as adjustments to this baseline fleet projection.

Table D-1 provides information on the baseline fleet for our analysis period (2017-2050). Note that our vehicle population only includes vehicles of MY 2029 and earlier. Figure D-1 provides a snapshot of the baseline fleet for 2030. This snapshot provides information on the underlying vehicle mix in terms of vehicle type (passenger car or light trucks) and vintage.

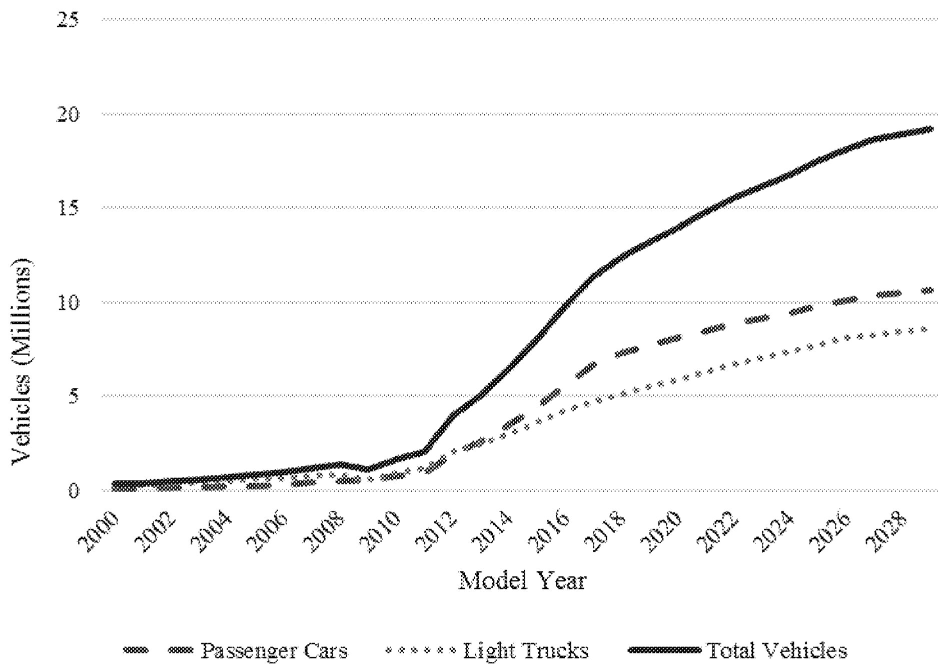
Table D-1. Baseline Fleet by Calendar Year (Millions of Vehicles)

	2017	2020	2025	2030	2035	2040	2045	2050
Passenger Cars	132.7	136.2	142.3	139.2	93.2	47.9	14.7	3.1
Light Trucks	106.9	109.7	114.7	112.2	75.8	43.0	20.4	8.0
Total Vehicles	**239.6**	**246.0**	**257.0**	**251.4**	**168.9**	**90.8**	**35.1**	**11.1**

Note: Consistent with the modeling reported by NHTSA/EPA in the PRIA, our analysis only considers MY 2029 vehicles and earlier.
Source: EPA MOVES 2014b (2018a).

[25] EPA MOVES 2014b (2018b).

Figure D-1. Baseline Vehicle Fleet by Model Year, for 2030



Source: EPA MOVES 2014b (2018a)

B. Changes in Existing Fleet due to New Vehicle Sales

NERA applied the results from the New Vehicle Market Model to the baseline fleet projections for MY 2017 to MY 2029 to estimate the impacts of changes in the new vehicle market due to the alternative CAFE standards. The New Vehicle Market Model allows us to estimate the percentage change in new vehicle sales for passenger cars and light trucks for each model year for which we have CAFE Model information on changes in vehicle costs and fuel economy (i.e., MY 2017 to MY 2032). We apply these percentage changes to model the impacts on new vehicle sales. For example, for the 2021 passenger car fleet, we adjust the number of MY 2021 passenger cars included in the baseline MOVES fleet, by the percentage changes in new vehicle sales that we estimate for each of the three CAFE alternatives using the results of the New Vehicle Market Model for MY 2021. We then carry forward that adjusted number of MY 2021 vehicles to the 2022 fleet, using the same process for the subsequent model year fleets through 2032. Note that only the costs and benefits associated with model years up to MY 2029 are included in the net benefits analysis.

C. Changes in Existing Fleet due to Scrappage Effects

NERA applied the results from the Scrappage Model to the baseline fleet projections for calendar years 2017-2050 to estimate the impacts of changes in vehicle scrappage rates due to increased new vehicle prices. The Scrappage Model allows us to separately estimate the impacts of changes to net new vehicle prices due to the alternative standards on the used vehicle population for passenger cars and light trucks for MY 1977 to MY 2029. We apply these estimated scrappage rates by vehicle age to the relevant model years in the baseline MOVES fleet population for each year.

Since our net benefits estimation considers the operation of these vehicles through calendar year 2050, this analysis requires assumptions about new vehicle prices and scrappage behavior beyond the years modeled in the CAFE and New Vehicle Market models. We assume that the percentage price difference that exists in the last year for which compliance is modeled in the CAFE Model (i.e., 2032) persists through to calendar year 2050. For example, if new vehicle prices are projected to be 3% higher in 2032 under the augural standards compared to another regulatory alternative, we assume prices will remain 3% higher in calendar years 2033-2050 and the price effects on scrappage will continue in those calendar years. As a sensitivity test, we assumed instead that new vehicle price effects would cease completely and scrappage rates would be identical across regulatory scenarios in calendar years 2033-2050; the net benefits results were not significantly affected by this sensitivity case.

D. Combined Effects on Fleet Population

The separate changes in new vehicle sales and changes in scrappage rates would lead to differences in the overall fleet size for the CAFE standard alternatives. The net effects of these two changes did not have a substantial effect on the overall fleet population under any of the three CAFE alternatives (never more than 0.25% change in fleet size compared to the augural standards).

E. References

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Appendix E: Vehicle Miles Traveled (VMT) Model

This appendix provides information on the VMT Model developed by NERA. The VMT Model includes the effects of two changes from the baseline values (Augural standard) due to the CAFE alternatives: (1) effects of changes in the vehicle fleet; and (2) effects of changes due to rebound effect.

A. Changes in VMT due to Age and Size of Fleet

The alternative standards affect both the numbers of new vehicles in the fleet (through impacts on new vehicle sales) and the numbers of old vehicle in the fleet (through impacts on scrappage rates). Less-stringent standards, for example, lead to greater new vehicles sales and greater used vehicle scrappage. These effects combine to produce a fleet with relatively more new vehicles than old vehicles under less-stringent standards. Since newer vehicles are typically driven more miles per year than older vehicles, this change in fleet composition can affect total fleet VMT, increasing VMT for less-stringent standards.

If the scrappage effect is larger than the sales effect, the combined effects may produce a smaller fleet under less-stringent standards. For example, if two additional used vehicles are retained for each lost new vehicle sale, the combined VMT of the two used vehicles may outweigh the lost VMT of the new vehicle. Changing fleet size can also affect total VMT.

The net effect of these two changes in the vehicle fleet on VMT was relatively small—the overall effect was never more than 0.02% change relative to VMT under the augural standards for any of the three CAFE alternatives.

B. Changes in VMT due to the Rebound Effect

Improvements in energy efficiency decrease the cost of energy consumption and thus lead to an increase in energy use; this well-known effect is called the "rebound effect." In the context of improvements in motor vehicle fuel efficiency, the rebound effect is defined as the elasticity of VMT with respect to fuel efficiency improvements, i.e., the percentage change in VMT associated with a one-percent change in fuel efficiency. (Reported elasticity estimates typically are multiplied by 100 so the rebound effect is expressed as a percentage, e.g., an elasticity of 0.2 is translated into a rebound effect of 20 percent, meaning that the percent increase in VMT is 20 percent of the percentage improvement in fuel efficiency.) Empirical estimates of the rebound effect are often based on estimated changes in VMT with respect to changes in fuel cost per mile or fuel price.

The VMT Model is based upon an evaluation of alternative estimates in prior studies. This is the approach taken by NHTSA/EPA in the PRIA.

1. Rebound Studies

NERA developed a table listing rebound estimates in the literature, drawing on the lists of studies cited by EPA and NHTSA in NHTSA/EPA's PRIA (2018b) and the EPA Proposed

Determination Technical Support Document (2016).[26] As in the PRIA, we focus on estimates of the long-run rebound effect.[27]

Table E-1 lists the studies in the NERA review. For each study, the table includes columns showing information on (a) the rebound effect range and (b) a most-likely value (if any) or an average value (if not most-likely value). The final rows of Table E-1 show the overall median and mean values across all studies based upon most-likely or average values. The mean rebound effect is 26% and the median rebound effect is 22%.

[26] E.g., see Section 3.4.2 of the EPA Proposed Determination (2016) and Section 8.9.6 of the NHTSA/EPA PRIA (2018b).

[27] See p. 968 of NHTSA/EPA PRIA (2018b).

Table E-1. Estimates of the Long-Run Rebound Effect in Various Studies

Author (Year)	Range	Suggested Value or Average Value	Time Period
Mayo & Mathis (1988)	26%	26%	1958-1984
Gately (1992)	9%	9%	1966-1988
Greene (1992)	5 - 19%	12%	1966-1989
Jones (1993)	30%	30%	1966-1989
Schimek (1996)	21 - 29%	25%	1950-1994
Greene, Kahn & Gibson (1999)	23%	23%	1979-1994
Pickrell & Schimek (1999)	4 - 34%	19%	1995
Puller & Greening (1999)	49%	49%	1980-1990
Haughton & Sarkar (1996)	22%	22%	1973-1992
West (2004)	87%	87%	1997
Small & Van Dender (2005)	22%	22%	1966-2001
Small & Van Dender (2007)	11%	11%	1997-2001
Barla et al. (2009)	20%	20%	1990-2004
Bento (2009)	21 - 38%	34%	2001
Wadud et al. (2009)	1 - 25%	13%	1984-2003
Hymel, Small & Van Dender (2010)	24%	24%	1966-2004
Hymel, Small & Van Dender (2010)	16%	16%	1984-2004
West and Pickrell (2011)	9 - 34%	22%	2009
Su (2012)	13%	13%	2009
Anjovic and Haas (2012)	44%	44%	1970-2007
Greene (2012)	8 - 12%	10%	1967-2006
Linn (2013)	20 - 40%	30%	2009
Frondel and Vance (2013)	46 - 70%	58%	1997-2009
Liu et al. (2014)	40%	40%	2009
Gillingham (2014)	22 - 23%	22%	2001-2003
Weber and Farsi (2014)	19 - 81%	50%	2010
West et al. (2015)	0%	0%	2009
Hymel & Small (2015)	18%	18%	2000-2009
DeBorger (2016)	8 - 10%	9%	2001-2011
Stapleton et al. (2016)	9 - 36%	19%	1970-2011
Stapleton et al. (2017)	14 - 30%	26%	1970-2012
Mean:		**26%**	
Median:		**22%**	

Notes: The mean and median were calculated using mid-points or suggested values for studies in which a range is reported.

Source: Studies included in Section 3.4.1 of the EPA Proposed Determination TSD (2016) and Table 8-8 of NHTSA/EPA PRIA (2018b). Note that NERA did not include the value of 0 included for the Goldberg (1996) study, as this estimate was based on the lack of statistical significance rather than a rebound estimate.

2. Average Rebound Values for Study Grouping

Differences in these studies can be evaluated based upon groups organized by date of the study and by geography. We consider whether there are systematic differences by decade and by broad geographic groupings. We also consider the potential changes over time due to future growth in per capita income.

The studies listed in Table E-1 were published between 1988 and 2017 and provide estimates of the long-run rebound effect ranging from zero to 87 percent. Grouped by decade, the studies do not appear to show a clear temporal trend in rebound estimates: (a) for studies published between 1990 and 1999, the average rebound effect is 24 percent; (b) for studies published between 2000 and 2009, the average rebound effect is 31 percent; and (c) for studies published between 2010 and 2017, the average rebound effect is 25 percent.

The studies include both domestic and international studies. Seven of the 30 studies in Table E-1 use data from regions outside of the United States (Canada, Great Britain, and the EU); the average rebound effect for these studies is 32 percent. Twenty-three of the 30 studies use U.S. data; the average rebound effect for these studies is 24 percent.

Several studies (e.g. Greene 2012 and Hymel & Small 2015) posit that the rebound effect should decrease as per capita incomes increase. The PRIA includes an evaluation of this issue.

3. Rebound Effect Used in the VMT Model

We use a rebound value of 20 percent in the VMT Model. This choice reflects our best professional judgement accounting for the results from the existing studies as well as the possibility that the rebound effect might decline in the future due to potential increases in per capita income.

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Appendix F: MOVES Model

This appendix describes how Trinity used the U.S. Environmental Protection Agency (EPA) Motor Vehicle Emissions Simulator (MOVES) vehicle emissions model to estimate the change in CO_2-equivalent and criteria pollutant emissions for the U.S. vehicle fleet due to the alternative CAFE standards. MOVES was developed by EPA to estimate criteria pollutant and CO_2-equivalent emissions from U.S. on-road motor vehicles over nationwide, regional and localized scales under a wide range of fleet characteristics, ambient and operating conditions. MOVES is based on exhaustive vehicle emission testing measurements collected under both laboratory and in-use conditions and is designed to estimate on-road vehicle fleet emissions and changes over time from on-going changes to federal new vehicle emission standards as well as local control programs.

A. Overview of MOVES Model

EPA regularly updates the model, generally as additional vehicle emission testing study data become available or when new vehicle emission certification or fuel standards are promulgated. The latest version of MOVES, MOVES2014b (released in August 2018) was used by Trinity to perform the analysis of changes in light-duty vehicle fleet tailpipe[28] emissions under different CAFE standard alternatives. Although NHTSA's vehicle emissions analysis presented in the NPRM was based on an earlier version, MOVES2014a, the on-road vehicle emissions portions of both MOVES versions are identical. (MOVES also estimates emissions from off-road vehicles and equipment and these elements were updated in MOVES2014b.)

Differences in vehicle emissions under various CAFE alternatives between this analysis and those published in the proposed rulemaking (Appendix D of the DEIS) are the result of several primary and secondary factors as follows:

- *Primary Differences*. Primary differences arise from the different input fleet forecast data used in the NERA/Trinity analysis versus that utilized by NHTSA within the CAFE Model. Specifically, NHTSA estimates fleet changes (projected sales, car vs. truck fleet shifts, scrappage-related age distribution impacts and VMT impacts from the rebound effect) using those internal modeling elements within the CAFE Model. The NERA/Trinity analysis used fleet forecasts and composition generated by NERA's New Vehicle Market, Scrappage, VMT and Fleet Population models to determine CAFE standard alternative vehicle fleet impacts.

- *Secondary Differences*. Small differences in emissions between NHTSA and NERA/Trinity estimates may have resulted from the fact that the NERA/Trinity MOVES runs were executed for a Yearly time aggregation level.[29] MOVES can be executed at

[28] MOVES only estimates on-road (i.e., tailpipe) vehicle emissions. Upstream emission impacts from different CAFE standard alternatives were estimated using a separate model, GREET, and are discussed in Appendix G of the report.

[29] MOVES can be executed at different time aggregation levels for which emissions are individually calculated between Yearly and Hourly levels. This Time Aggregation run option significantly affects the model's execution time. Hourly level executions can take between and 25-50 times longer to complete than Yearly level runs, depending on the pollutants and emission processed included in the run. There was not sufficient time to complete a full set of Hourly time aggregation level runs within the NPRM comment period. A comparison of Yearly vs. Hourly time aggregated outputs for one CAFE scenario (augural

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different time aggregation levels from Yearly down to Hourly calculation levels. Hourly-based emissions (summed to annual estimates) tend to be nominally higher than those based on the Yearly Time Aggregation option. MOVES can only calculate evaporative VOC emissions when run in Hourly mode (to account for diurnal temperature impacts). Although evaporative VOC emissions are a significant fraction of total VOC emissions for late-model light-duty gasoline vehicles, their impact on the overall net cost-benefit analysis is believed to be marginal. As noted in both the PRIA and DEIS, the agencies also excluded evaporative VOC emissions from their tailpipe emission estimates.

B. MOVES Inputs and Run Configuration Options

Table F-1 lists the MOVES modeling settings used to generate light-duty vehicle U.S. fleet emissions impacts under each CAFE standards alternative evaluated. It is divided into two sections. The first model command file (called a "Runspec" in MOVES terminology) options that were used are enumerated. The term "Source Use Type" in these tables is a use type vehicle categorization used by MOVES (to reflect how vehicles operate differently), rather than regulatory class categorization scheme. Source Use Types encompassing the light-duty vehicle fleet include Passenger Cars (which align with the passenger car regulatory category), Passenger Trucks and Light Commercial Trucks, which span the 8,500 lb GVW cutoff between the light- and heavy-duty vehicle regulatory classes (as well at the 10,000 lb GVW limit for medium-duty passenger vehicles under CAFE). MOVES uses an internal allocation scheme to map between the Source Use Type and Regulatory Class-based vehicle categories.[30] Thus as listed under the Output Emissions Detail setting in Table F-1, emissions outputs by regulatory class were selected to align with the passenger car and light truck CAFE definitions (including Class 2a medium-duty passenger vehicles).

standards) was performed. Tailpipe emissions under the Yearly time aggregation were found to be 2-14% lower than those from the Hourly option run across all pollutants with the exception of VOC as explained above.

[30] Table A, "MOVES2014, MOVES2014a and MOVES2014b: Technical Guidance, Using MOVES to Prepare Emission Inventories for State Implementation Plans and Transportation Conformity," U.S. Environmental Protection Agency, Report No. EPA-420-B-18-039, August 2018.

Table F-1. MOVES Modeling Settings

Setting	Value
Runspec/Command File Options	
MOVES Version	MOVES2014b-20180726
Time Aggregation Level	Yearly
Years	2016-2030, 2035, 2040, 2045, 2050
Months/Hours/Days	All
Geographic Bounds	Nationwide (entire U.S.)
Vehicles	Light Commercial Truck, Passenger Truck, Passenger Car. All Fuel Types.
Road Types	All
Pollutants (criteria)	NOx, CO, VOC, SO_2, and $PM_{2.5}$ and PM_{10} (Total, brake wear, and tire wear)
Pollutants (greenhouse)	CO_2 eq, CO_2, Methane, Nitrous Oxide
Output Emissions Detail	Outputs disaggregated by Model Year, Fuel Type, Emission Process, Source Use Type and Regulatory Class
Input Database Elements	
Vehicle Type VMT	Annual VMT by Source Type from NERA modeling
Source Type Population	Populations by Source Type from NERA modeling
Age Distribution	Vehicle population fractions by age (years) for each Source Use Type and calendar year combination

Below these "Runspec" options, input database elements that were changed from MOVES nationwide default values are also listed in Table F-1. These inputs include VMT by Source Use Type and calendar year, vehicle populations by Source Use Type and calendar year and vehicle age distributions and revised the revised fleet activity forecast for each CAFE alternative developed by NERA. The Vehicle Type VMT and Source Type Population inputs reflect NERA's accounting for the rebound effect and vehicle choice modeling, respectively. The Age Distribution input accounts for scrappage-related effects.

Unless explicitly listed in Table F-1, all other MOVES inputs and run settings were based on MOVES default values.

C. MOVES Post-Processing

The MOVES model is built around the MySQL relational database platform. As a result, its outputs (in the form of MySQL databases and tables) were exported and post-processed into spreadsheets for easier dissemination, and to perform various summary tabulations on the model outputs (for example summing emissions by model year for a calendar year fleet).

Beyond the exporting and summary tabulation elements, CO_2 emission adjustments were applied to MOVES outputs for all CAFE alternatives except the augural standards scenario. Unlike the CAFE Model, MOVES does not directly evaluate CO_2-equivalent emission impacts of alternative CAFE standards; CO_2-equivalent outputs from MOVES reflect the adopted augural standards. Adjustments were thus made to MOVES CO_2 emission outputs to reflect fuel economy/CO_2 emission rate differences between the augural standards and the CAFE alternative evaluated. These adjustments were based on ratio of the alternative CAFE scenario standard to that of the augural standards, the "reference" fuel economy/CO2 hardcoded into MOVES. These adjustment ratios were calculated by vehicle type (passenger car and light truck) and model year. They were based on the industry fleet average required fuel economy (in miles per gallon) contained in the "Standard" field in the Compliance Report output for the mainstream "Scenario 1-4 CAFE Model runs described in the CAFE Model Appendix (Appendix A).

D. References

National Highway Traffic Safety Administration (NHTSA), 2018. "Draft Environmental Impact Statement: The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Year 2021-2026 Passenger Cars and Light Trucks." *Docket No. NHTSA-2017-0069*. July.

U.S. Environmental Protection Agency (EPA). 2018. "MOVES2014, MOVES2014a and MOVES2014b: Technical Guidance, Using MOVES to Prepare Emission Inventories for State Implementation Plans and Transportation Conformity," *Report No. EPA-420-B-18-039*, August.

U.S. Environmental Protection Agency (EPA) and National Highway Traffic and Safety Administration (NHTSA), 2018b. "Preliminary Regulatory Impact Analysis (PRIA): The Safer Affordable Fuel-Efficient (SAFE) Vehicles rule for Model Years 2021–2026 Passenger Cars and Light Trucks." July.

Appendix G: Upstream Emissions Modeling

This appendix provides information on the modeling used to develop estimates of upstream emissions due to the alternative CAFE standards considered in this study. Upstream emissions refer to the emissions associated with fuel production including crude oil production, fuel refining, and fuel distribution and storage. We first provide a discussion of the methodology used by NHTSA/EPA as described in the PRIA, on which our estimates are based. We then provide information on how we implement the NHTSA/EPA PRIA methodology using our estimates of changes in fuel consumption as summarized in Figure 6.

A. NHTSA/EPA PRIA Upstream Emissions Factors

To develop upstream emissions estimates we rely on the upstream emissions factor estimates used by NHTSA/EPA in the PRIA that are included in the CAFE Model parameters file. The PRIA notes that the upstream emission factors relied on by the agencies for each fuel type are based on the energy content and emission rates per unit of fuel energy refined and distributed, as developed using the Greenhouse Gases and Regulated Emissions in Transportation (GREET) Model developed by Argonne National Laboratories.

The upstream emissions factor values included in the CAFE model parameters files include upstream emissions factor estimates (g/MMBtu) for CO, VOC, NO_X, SO_X, $PM_{2.5}$, CO_2, CH_4, and N_2O. Separate upstream emissions values are reported for the following activities for each relevant fuel type: petroleum extraction, petroleum transportation, petroleum refining, and fuel transportation, storage, and distribution (TS&D).

For the criteria pollutant emissions, (i.e., pollutants for which ambient air quality standards have been developed or precursor pollutants), the factors associated with these activities are then scaled to reflect the share of such activities that are expected to occur within the United States. For gasoline for example, the NHTSA/EPA PRIA states that it assumed that 50% of increased gasoline consumption would be supplied by increased domestic refining and that 90% of this additional refining would use imported crude petroleum. The NHTSA/EPA PRIA criteria pollutant upstream values accordingly include 5% of the total petroleum extraction and transportation emissions, 50% of the total petroleum refining emissions, and 100% of the fuel TS&D emissions. The PRIA indicates that estimates of criteria pollutant emissions are for domestic emissions only.[31]

For CO_2 and CH_4, the NHTSA/EPA PRIA emissions factors do not include any domestic scaling, but rather include all relevant upstream emissions regardless of where the actual upstream activity is assumed to take place. The PRIA does not include an explanation of this treatment of the two greenhouse gas (GHG) emissions, although it presumably reflects the global nature of the effects of GHG emissions. Note that the social cost of carbon (SCC) values used in the PRIA to develop dollar values include only the domestic valuation of GHG emissions.

There is one exception in the treatment of GHG emissions in the PRIA. For N_2O, the upstream emissions factors include the same scaling as the criteria pollutants. We presume this is an error,

[31] See e.g., footnote 657 on p. 1215 or p. 1303, NHTSA/EPA PRIA (2018b)

as N_2O is a GHG whose impacts should presumably be treated the same as CO_2 and CH_4. The PRIA does not include an explanation for why N_2O is treated differently than the other GHGs.

B. NERA Implementation of NHTSA/EPA PRIA Upstream Emissions Factors

We develop upstream emissions estimates for the alternative CAFE standards by multiplying the NHTSA/EPA PRIA upstream emissions factors by the changes in fuel consumption that we estimate based on our fleet population and VMT modeling. We outline the key implementation steps and adjustments we make below.

1. Adjustments to NHTSA/EPA PRIA Upstream Emissions Factors

a. Convert Factors to Grams per Gallon

We convert these values (which are in grams per million BTUs) to grams per gallon based on the energy density assumptions for each relevant fuel type included in the CAFE Model parameters file. These energy density assumptions are summarized in Table G-1 below.

Table G-1. NHTSA/EPA PRIA Energy Density Assumptions by Fuel Type (Btu/gallon)

Fuel Type	Energy Density (Btu/gallon)
Gasoline	115,219
Diesel	82,294
Ethanol-85	129,488

Source: CAFE Model parameters file available on NHTSA website.

b. Adjust Ethanol-85 Import Assumptions

The CAFE model parameters file notes that for Ethanol-85 (E85) the share of fuel savings leading to reduced domestic fuel refining would be 0.075 (i.e., a 1-gallon reduction in E85 consumption would decrease domestic fuel refining by 0.075 gallons). The model parameters file notes that this figure is calculated as 15% of the domestic fuel refining assumption for gasoline (i.e., E85 contains 15% petroleum content, and NHTSA/EPA assume in the PRIA that a decrease in gasoline consumption would lead to a 50% reduction in domestic fuel refining). Note however that the NHTSA/EPA PRIA parameters file indicates that within this 0.075 reduction in domestic fuel refining, the share of domestic refining from domestic crude oil for E85 would be 0.015 and the share of domestic refining from imported crude oil for E85 would be 0.135. This sum (share of domestic crude + share of imported crude) does not add to one, which we presume is an implementation error due to an effective double counting of the 15% E85 adjustment. Note that this error would somewhat understate the upstream emissions estimates associated with changes to E85 consumption. To avoid understating the emissions impacts associated with E85, we use the 0.075 domestic fuel refining assumption and then apply the same assumption related to the relative share of domestic crude oil (10%) and imported crude oil (90%), as that used for gasoline and diesel above.

c. Adjust N_2O Upstream Emissions Factors

As noted, the upstream emissions factors used by NHTSA/EPA PRIA for N_2O include the same scaling to estimate domestic emissions only as the criteria pollutants. We presume this is in error, as N_2O is a GHG whose impacts should be treated the same as CO_2 and CH_4. The PRIA does not include an explanation for why N_2O is treated differently than the other GHGs. Accordingly, we remove any domestic scaling from the N_2O upstream emissions factors, such that the N_2O emissions factors are consistent with the other GHGs.

2. NERA-Adjusted Upstream Emissions Factors

Table G-2 summarize the factors we rely on below by fuel type for each relevant pollutant. For ease of exposition, results are provided for every fifth year. Note that for the emissions tables included in Chapter III of this report, we convert CH_4 and N_2O to CO_2 equivalents based on the as an assumed global warming potential (GWP) value for CH_4 of 25 and a GWP of 298 for N_2O as reported by EPA (2017).[32] To develop the upstream emissions estimates we multiply these upstream factors by the estimated changes in fuel consumption due to the alternative standards as provided in Figure 6.

[32] See EPA (2017) "Greenhouse Gas Equivalencies Calculator." https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Table G-2. Upstream Emissions Factors by Fuel Type (grams/gallon)

Calendar Year	Source	CO	VOC	NO_X	SO_2	PM	CO_2	CH_4	N_2O
2020	Gasoline	0.8	2.8	1.8	1.6	0.1	2,362.6	21.2	0.5
	Diesel	0.4	0.3	0.8	0.5	0.1	1,829.7	22.0	0.0
	E85	2.2	4.4	5.9	4.6	0.4	246.7	1.9	0.1
2025	Gasoline	0.8	2.9	1.6	1.2	0.1	2,230.6	19.6	0.3
	Diesel	0.4	0.3	0.8	0.5	0.1	1,829.7	22.0	0.0
	E85	2.2	4.4	5.9	4.6	0.4	246.7	1.9	0.1
2030	Gasoline	0.8	2.9	1.6	1.2	0.1	2,209.9	19.6	0.3
	Diesel	0.4	0.3	0.8	0.5	0.1	1,809.0	22.0	0.0
	E85	2.2	4.4	5.9	4.6	0.4	246.7	1.9	0.1
2035	Gasoline	0.8	2.9	1.6	1.1	0.1	2,206.4	19.6	0.3
	Diesel	0.4	0.3	0.8	0.5	0.1	1,806.4	22.0	0.0
	E85	2.2	4.4	5.9	4.6	0.4	246.7	1.9	0.1
2040	Gasoline	0.8	2.9	1.6	1.1	0.1	2,200.7	19.6	0.3
	Diesel	0.4	0.3	0.8	0.5	0.1	1,801.2	22.0	0.0
	E85	2.2	4.4	5.9	4.6	0.4	246.7	1.9	0.1
2045	Gasoline	0.8	2.9	1.6	1.1	0.1	2,196.1	19.6	0.3
	Diesel	0.4	0.3	0.8	0.5	0.1	1,796.0	22.0	0.0
	E85	2.2	4.4	5.9	4.6	0.4	246.7	1.9	0.1
2050	Gasoline	0.8	2.9	1.6	1.1	0.1	2,193.8	19.6	0.3
	Diesel	0.4	0.3	0.8	0.5	0.1	1,793.4	22.0	0.0
	E85	2.2	4.4	5.9	4.6	0.4	246.7	1.9	0.1

Note: Values in grams per gallon.
Source: CAFE Model parameters file and NERA adjustments as explained in text.

C. References

U.S. Environmental Protection Agency (EPA), 2017. "Greenhouse Gas Equivalencies Calculator." https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

U.S. Environmental Protection Agency (EPA) and National Highway Traffic and Safety Administration (NHTSA), 2018b. "Preliminary Regulatory Impact Analysis (PRIA): The Safer Affordable Fuel-Efficient (SAFE) Vehicles rule for Model Years 2021–2026 Passenger Cars and Light Trucks." July.

Appendix H: Private Costs and Benefits of Alternative CAFE Standards

This appendix provides information on the data and methods used by NERA to assess changes in consumers' private costs and benefits due to the alternative CAFE standards. The level of CAFE standards stringency will affect both the cost and the driving value of new vehicles through the standards' impact on the application of fuel economy technologies. Greater technology application under more stringent standards, for example, will increase the prices consumers must pay for new vehicles but will also provide consumers with benefits from the higher fuel economy of these vehicles. The following sections describe the specific calculations we use to estimate those costs and benefits across CAFE standard alternatives.

A. Consumer Technology Costs of Increased Fuel Economy

Technology costs are calculated as the retail value of any additional technologies adopted for compliance with CAFE standards, aggregated across all new vehicle sales. The costs of the technologies and the manufacturers' choice of which technologies to apply to each vehicle models are outputs of the CAFE model. For estimating costs of these technologies to consumers, the CAFE model assumes a retail price equivalent (i.e., a "mark-up") of 1.5 for fuel economy technologies.

For a particular model year, the total technology cost due to the CAFE standards is calculated using a similar formulation as that employed by NHTSA/EPA in the PRIA:

$$\boldsymbol{TechCost_{MY}} = \sum_{C} \left(\boldsymbol{TechCost_{C,MY}} \times \boldsymbol{Sales_{C,MY}} \right) \quad \mathbf{(15)}$$

Where:

$TechCost_{C,MY}$	: The sales-weighted average of retail cost of fuel economy technologies applied for vehicles in class C in model year MY, estimated using technology costs from the CAFE model
$Sales_{C,MY}$	: The sales of vehicles in class C in model year MY

B. Consumer Benefits of Increased Vehicle Fuel Economy

Vehicles with greater fuel economy provide benefits to consumers including (a) potential fuel savings for a given distance of travel, (b) increased mobility through the ability to afford more miles of travel, and (c) time savings of an increased driving range. The estimation of each of these components is described below.

1. Valuation of Changes in Fuel Economy to New Vehicle Purchasers

An improvement to a vehicle's fuel economy provides purchasers with prospective fuel savings over the course of the vehicle's operation. The actual dollar value of those fuel savings to new vehicle purchasers depends upon many uncertain factors, including the potential miles traveled, the potential fuel prices, the number of years of ownership, and the likely opportunity cost of selling the vehicle as a used vehicle. From the new vehicle purchaser's point of view, the present value of potential fuel savings depends on the discount rate they might apply to future fuel savings, which would incorporate the various uncertainties.

To capture this valuation of the prospective fuel savings, we measure the value consumers are observed to place on the prospective fuel savings afforded by improved fuel economy using the estimates of fuel economy changes from the CAFE model and NERA's estimate of consumers' willingness-to-pay for such changes from the New Vehicle Market Model. This estimation is calculated using the equation below.

$$\boldsymbol{ValuationFE_{C,MY,CY}} = \sum_{C} \left(\boldsymbol{CPM_{i,C,MY,CY}} - \boldsymbol{CPM_{i,C,2016,CY}}\right) \times \boldsymbol{WTP} \times \boldsymbol{Sales_{i,C,MY}} \qquad \textbf{(16)}$$

Where:

$CPM_{i,MY,CY}$	: The average cost per mile of model year *MY* vehicles in class *C* in calendar year *CY* in scenario *i*
$CPM_{i,2016,CY}$	: The average cost per mile of baseline fleet (i.e., MY 2016) vehicles in class *C* in calendar year *CY* in scenario *i*
WTP	: Consumers' willingness to pay for dollar-per-mile reduction in fuel costs; estimated to be $694 in the New Vehicle Market Model
$Sales_{i,C,MY}$	: Sales of model year *MY* new vehicles in class *C*

2. Valuation of Changes in Vehicle Miles of Travel

Increased fuel economy lowers the cost-per-mile of travel and allows drivers to afford increased mobility. Specifically, from a baseline level of miles, the decrease in cost-per-mile will lead drivers to increase VMT until the marginal benefit of an additional mile is equal to the marginal cost of the next mile. We estimate the value of these "rebound" miles between the augural standards baseline and the three CAFE alternatives using the costs-per-mile in the two relevant scenarios, as shown in the equation below. Consistent with NHTSA/EPA's treatment of the rebound mobility benefit in the PRIA, this conceptually captures both (a) the value offsetting the fuel cost of traveling those miles and (b) the additional consumer surplus from the fact that the value of these additional miles exceeds the cost.

$$\boldsymbol{ReboundMilesValue_{i,MY,CY}} = \sum \left(\begin{array}{c} \left(\boldsymbol{ReboundMiles_{i,MY,CY}}\right) \times \\ \left(\dfrac{\boldsymbol{CPM_{i,MY,CY}} + \boldsymbol{CPM_{0,MY,CY}}}{\mathbf{2}}\right) \end{array} \right) \qquad \textbf{(17)}$$

Where:

ReboundMiles	: The number of rebound miles traveled by model year *MY* vehicles in calendar year *CY* in scenario *i*
$CPM_{i,MY,CY}$	: The average cost per mile of model year *MY* vehicles in calendar year *CY* in scenario *i*
$CPM_{i,MY,CY}$	: The average cost per mile of model year *MY* vehicles in calendar year *CY* in scenario *i*

For total social benefits from changes in mobility, we aggregate across the values for the model years whose fuel economies are affected by the standards (i.e., MY 2017-2029) and across all calendar years in which these vehicles are driven.

3. Valuation of Changes in Driving Range

Finally, changes in the fuel efficiency of vehicles will affect the driving range for a given quantity of fuel (assuming the sizes of gas tanks do not change). Improved fuel economy would allow consumers to spend less time refueling, providing time saving benefits in addition to the fuel savings and greater mobility benefits discussed above. We follow the formulation used in the NHTSA/EPA PRIA for estimating the value to consumers from reduced refueling time, with one minor difference. Specifically, in the absence of accurate data on fuel tank sizes for vehicle models by model year, we use a simplifying assumption of an average tank size equal to 17 gallons. Using NHTSA's value for average percent of fuel tank refilled of 65%, this translates into a need to refuel every 11.05 gallons. This is used in the following equation to estimate the value of changes in driving range associated with the CAFE standards.

$$\boldsymbol{RefuelValue_{MY,CY}} = \sum \left(\left(\frac{\boldsymbol{RefuelTime_{Fixed}} + \frac{\boldsymbol{11.05}}{\boldsymbol{RefuelTime_{Variable}}}}{\boldsymbol{60}} \right) \times \left(\frac{\boldsymbol{G'_{MY,CY}}}{\boldsymbol{11.05}} \right) \boldsymbol{x\,TravelValue} \right) \quad \textbf{(18)}$$

Where:

$RefuelValue_{MY,CY,FT}$	: Refueling time benefit for model year *MY* vehicles in calendar year *CY*
RefuelTime	: A fixed component of refueling time; we use NHTSA's value of 3.5 minute
$RefuelTime_{Variable}$	: The variable component of refueling time; we use NHTSA's value of 7.5 gallons per minute
$G'_{MY,CY}$	: Gallons of fuel consumed by model year *MY* vehicles in calendar year *CY*
TravelValue	: Value of travel time per vehicle; we use NHTSA's value of $18.83 per hour

To obtain an estimate of total social benefits from changes in driving range due to the alternative CAFE standards, we aggregate across all model years and calendar years in the analysis.

C. References

U.S. Environmental Protection Agency (EPA) and National Highway Traffic and Safety Administration (NHTSA), 2018b. "Preliminary Regulatory Impact Analysis (PRIA): The Safer Affordable Fuel-Efficient (SAFE) Vehicles rule for Model Years 2021–2026 Passenger Cars and Light Trucks." July.

Appendix I: Crash Costs

This appendix provides information on the data and methods used by NERA to estimate the potential safety externalities associated with the alternative standards. We first include a discussion of our methodology, which we develop based on the NHTSA/EPA PRIA methodology. We then present results for estimates of the safety impacts based on the results of our fleet population modeling.

A. Overview of Methodology

The PRIA considered the effects of three potential factors due to the alternative CAFE standards on vehicle safety:

1. Effects of differences in vehicle mass related to adoption of various technologies.
2. The increase in the pace of consumer acquisition of newer safer vehicles that results from lower vehicle prices associated with technologies to meet less stringent CAFE standards.
3. Decreased driving because of lower fuel economy.

In the following subsections, we first evaluate the likely significance of each of these factors. For the two categories that we determine to be likely significant we then calculate the associated changes in safety costs by implementing the following steps:

1. Translate the fleet changes due to the standards into changes in fatalities.
2. Develop a dollar value estimate of that change in fatalities by applying an appropriate value of statistical life parameter.
3. Calculate the costs associated with changes in non-fatal crash costs as a function of the fatal crash costs.

1. Changes in Vehicle Mass

One way for manufacturers to meet higher CAFE standards is by producing lighter vehicles. If lighter vehicles are also less safe, fuel economy-related changes in vehicle mass may impact vehicle safety.

The NHTSA/EPA PRIA includes a review of studies and an analysis of historical crash data to evaluate the effects of vehicle mass and size on safety. The results of the analysis are shown in Table 11-1 of the NHTSA/EPA PRIA. These results indicate that none of the fatality-increase-per-mass-reduction estimates are statistically significant. Because of the lack of statistical significance and because the NHTSA/EPA PRIA also indicates that the curb weight effects are small relative to the other two effects on crash costs they estimate,[33] we do not consider effects of changes in vehicle mass on crash costs.

[33] Table 11-24 on p. 1414 of PRIA.

2. Changes in Fleet Population

The NHTSA/EPA PRIA indicates that because newer cars have more safety features, an increase in the rate of acquisition of newer vehicles due to a decrease in the price of new vehicles may result in higher safety for the fleet of vehicles. Additionally, lower new vehicle prices mean that old vehicles are scrapped at a higher rate, removing older vehicles with fewer safety features from the fleet. Thus, sales and scrappage effects of less stringent standards combine to produce a newer fleet with safer vehicles, all else equal.

NERA uses the results of the Fleet Population Model as an input in the crash cost methodology from the NHTSA/EPA PRIA to estimate the effects of changes in the age-distribution of the vehicle fleet from the CAFE alternatives on crash costs.

3. Changes in VMT

The NHTSA/EPA PRIA indicates that the number of accidents is related to the VMT driven, with accidents increasing with increasing VMT. For changes in driving due to the rebound effect, however, the NHTSA/EPA PRIA notes that crash costs need not be evaluated because they are included in drivers' decisions to change the number of miles they drive. Because drivers are assumed to be aware of the risk of driving when they make the determination to drive extra miles due to the rebound effect, the miles are driven because they receive an equal and offsetting benefit from driving the miles. Thus, the NHTSA/EPA PRIA assumed that consumers that drive rebound miles fully internalize crash costs. Based on this assumption, crash costs from rebound miles would be included both in societal costs and societal benefits, resulting in zero net societal benefits. Following this logic, NERA does not consider rebound miles in its calculation of crash costs, although we note that changes in rebound miles might lead to crash costs to other drivers, costs that would not be internalized. The NHTSA/EPA PRIA does not provide information to develop estimates of this potential external effect of changes in rebound-related VMT. To the extent that the CAFE alternatives lead to fewer rebound-mile crashes, reductions in external crash costs would lead to social cost savings that are not included in our estimates.

4. Calculating Fatalities

Based on our evaluation of the above criteria, we calculate fatalities associated with changes in acquisition of new vehicles due to the alternative standards. As described below, we rely on the methodology for calculating changes in fatalities as described in the NHTSA/EPA PRIA and CAFE Model documentation, with an adjustment to ignore any effects due to mass change effects.

Note that VMT is an input into the calculation. The section above regarding increased driving has to do with the rebound effect; non-rebound VMT, however, is used as input in determining the number of fatalities.

B. Modeling of Crash Costs in NHTSA/EPA PRIA

NHTSA/EPA use the following equation (Equation 92 from the CAFE Model documentation) to calculate the number of fatalities F for vehicles of a given model year (MY) and fuel type (FT) in a given calendar year (CY).

$$F_{MY,CY,FT} = \sum_{i \in V} \left(\frac{M'_{i,MY,CY,FT}}{1e9} \, x \, MAX(28.58895 + FixedEffect_{MY}, 2) \, x \left(1 + Effect_{SC_i,CW_i} \, x \, \frac{T_{SC_i} - CW_i}{100}\right) \right) \quad (19)$$

The components can be separated to show the effects of the three factors:

$\frac{M'_{i,MY,CY,FT}}{1e9}$	Billions of miles driven by all vehicles of model *i*: more miles travelled will result in more fatalities
$MAX(28.58895 + FixedEffect_{MY}, 2)$	Vintage fixed effects for number of vehicle related fatalities per billion miles (two, the lowest value seen in the data for fatalities per billion miles, is used as a lower bound). Later model years will have lower (more negative) values for the fixed effect, lowering the fatalities estimates for those newer model years.
$\left(1 + Effect_{SC_i,CW_i} \, x \, \frac{T_{SC_i} - CW_i}{100}\right)$	Curb weight effects by safety class (PC, SUV/Truck, CUV/Minivan). Each class has a "threshold" T_{SCi} representing the boundary between small and large weight effects. Above and below those thresholds, the number of fatalities will change according to the Effect parameter's percent change in fatalities per 100lb change in curb weight.

Parameters used for the model year fixed effects, the safety class thresholds, and the fatality-curb weight elasticity are available in the CAFE Model parameters reference file available on NHTSA's website. The model year fixed effects are estimated in a regression of fatalities per VMT against model year fixed effects and polynomials in vehicle age. For the safety class thresholds and the fatality-curb weight elasticities, the PRIA updated the Kahane (2012), Puckett (2016), and Kindelberger/Draft TAR (2016) analyses that use logistic regressions by vehicle class and crash type to estimate the relationships between fatality per VMT rates and vehicle mass.

C. Overview of NERA Modeling of Crash Costs

NERA followed the methodology for calculating fatalities described by NHTSA/EPA in the PRIA with several changes:[34]

1. The VMT input used is the non-rebound VMT from the Fleet Population model.
2. The effects of curb weight are not included.
3. Since curb weight is not included, it is no longer necessary to aggregate from the individual vehicle level. Note that in the equation below, there is no summation over all vehicles within each model year, calendar year, and fuel type.

[34] As with the other parameters developed by EPA and NHTSA, NERA has not evaluated the underlying data and analysis behind the NHTSA safety analysis; thus the use of these parameters does not constitute confirmation of their validity.

We do not treat vehicles of different fuel types separately because the remaining components of the model are not unique to fuel type. NERA used the following equation:

$$F_{MY,CY} = \frac{MI'_{MY,CY}}{1e9} x\ MAX(28.58895 + Fixed\ Effects_{MY}, 2) \quad (20)$$

The fixed effects for the vintage-specific safety component used in this model are those provided in parameters file that accompanies the PRIA.

D. Methodology for Calculating Results for Fatal Crash Costs

Total fatality crash costs are then calculated using a cost-per-fatality parameter.

$$FatalityCosts_{MY,CY} = F_{MY,CY}\ x\ FatalityCost \quad (21)$$

The PRIA uses $9.9 million as the societal value of an additional statistical fatality. This value is based on the value of a statistical fatality determined in the NHTSA/EPA PRIA, which is derived from data in Blincoe et al. (2015), adjusted to 2016 dollars and updated to reflect the DOT guidance on the value of a statistical life in 2016. The NHTSA/EPA PRIA indicates that fatality costs include fatalities to all occupants of all vehicles involved in collisions, plus any pedestrians.

E. Results for Non-Fatal Crash Costs

Non-fatal crash costs include the value of non-fatal injuries and property damage. Non-fatal crash costs are calculated by applying a scaling factor to the value of fatality crash costs:

$$NonFatalCrashCosts = FatalityCosts\ x\ NonFatalCostsScalar \quad (22)$$

The non-fatal costs scalar is included in Table 11-24 of the NHTSA/EPA PRIA. As seen in the Central Analysis parameters file, the PRIA used 0.39 as the fatalities portion of crash costs factor. The fatalities portion of crash costs factor used by NERA was 0.4323, which is the unweighted fatalities portion of crash costs factor associated with sales and scrappage.

F. References

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U.S. Environmental Protection Agency (EPA) and National Highway Traffic and Safety Administration (NHTSA), 2018b. “Preliminary Regulatory Impact Analysis (PRIA): The Safer Affordable Fuel-Efficient (SAFE) Vehicles rule for Model Years 2021–2026 Passenger Cars and Light Trucks.” July.

Appendix J: Petroleum Market Externality Benefits

This appendix provides information on the data and methods used by NERA to assess the external benefits from changes in U.S. fuel consumption on petroleum markets. We focus this appendix on estimates of the "oil security premium"—measured in terms of dollars per barrel—due to changes in the consumption of imported oil and domestic oil. To develop estimates of potential petroleum market external benefits from the CAFE standard alternatives, we combine estimates of the "oil security premium" along with estimates of changes in domestic and imported crude oil due to the alternatives. The basic case we present in the main body of the report is based upon the average values for imported and domestic security premiums contained in a recent (2018) literature review. As sensitivity cases, we show results based upon different estimates of the security premium, including that used in the NHTSA PRIA as well as others provided in the recent literature review.

A. Overview of Methodology to Estimate the Oil Security Premium

1. Potential Factors Included in the Oil Security Premium

Changes in U.S. fuel consumption would lead to changes in the demand for crude oil, which is traded actively on a worldwide market. Interest in quantifying an "oil security premium" grew out of concerns about large U.S. dependence on imported oil and the prominent oil supply disruptions of the 1970s and the resulting "oil price shocks" that were believed to affect the overall U.S. gross domestic product (GDP). In recent years, the United States has become much more self-reliant in producing oil, and recent literature suggests that the U.S. GDP may be less sensitive to world oil price shocks than was previously estimated (Brown 2018).

The following is a summary of three factors that have been identified as potential elements of an "oil security premium." Note that in terms of the benefits assessments in this study, a critical question is whether these effects lead to external impacts, i.e., impacts that are not reflected in market transactions.

1. *U.S. petroleum demand and its effect on global prices and U.S. monopsony power.* An increase in U.S. petroleum demand due to less stringent CAFE standards means that the U.S. would purchase more petroleum. Since global demand is the sum of individual countries' domestic demand, this increase in U.S. demand would translate into an increase in global demand, which would put upward pressure on global petroleum prices. Note, however, that the increased oil price would represent a transfer from consumers to producers rather than an overall cost. There is a related argument that the U.S. is a major oil consumer and can exercise monopsony power, i.e., market power in buying oil on the world market. As noted in Brown (2018), however, the opportunity to exercise market power in buying oil on the world also represents a transfer (i.e., pecuniary externality) rather than a security issue; moreover, such opportunities to exercise market power are dependent upon stable market conditions rather than oil supply disruptions.

2. *Macroeconomic costs of U.S. petroleum consumption (i.e., effect of price shocks).* Changes in U.S. petroleum demand may expose the U.S. economy to risks associated with petroleum supply disruptions, including losses in U.S. GDP. Disruptions to global oil supply can trigger rapid increases in oil prices, which can impose significant costs on an economy, depending on that economy's dependence on petroleum-based products and the availability of substitute energy sources. As noted in the PRIA and in Brown (2018), there is considerable uncertainty regarding the potential significance and continued relevance of economic damages to the U.S. economy from oil supply disruptions and/or oil price shocks, given increased elasticity of oil demand and reduced sensitivity of GDP to oil price shocks. Some recent studies suggest that the potential macroeconomic costs associated with changes to oil prices are likely to be small or trivial.[35] Other studies indicate that there may be somewhat positive economic outcomes associated with oil price shocks.[36] For instance, Nordhaus (2007) and Blanchard & Gali (2010) assert that the U.S. economy expanded after the most recent oil price shock. There is additional recent research, however, suggesting that oil price shocks pose a continued macroeconomic risk, particularly considering the declining sensitivity of petroleum demand to price changes.[37] Despite this uncertainty, this factor constitutes a potential externality that market participants do not include in their demand and supply decisions.

3. *Potential effects of fuel consumption and petroleum imports on U.S. military spending.* Prior studies have suggested that changes in U.S. petroleum demand would affect U.S. military spending to secure the supply of oil imports from potentially unstable regions The PRIA assesses how U.S. military spending has varied historically (1962-2017, specifically) in relation to petroleum consumption and petroleum imports, concluding that there is no relationship between U.S. military spending and either petroleum consumption or petroleum imports.

2. Summary of External Factors Included in Oil Security Premium

The following is a summary of our assessment of the factors that should be included in assessing the size of an oil security premium.

1. Impacts on world oil prices and potential changes in U.S. monopsony power are not external security factors and should not be included in the oil security premium.

2. Potential impacts on U.S. GDP due to oil supply disruptions and oil price shocks are external security factors that should be included in the potential oil security premium.

3. Potential effects on U.S. military spending is not a likely effect of changes in U.S. oil consumption and thus should not be included in the oil security premium.

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[35] National Research Council (2009).

[36] Nordhaus (2007; Blanchard and Gali (2010).

[37] Hamilton (2012), Ramey and Vine (2012); Baumeister and Van Robays (2010).

B. Estimates of Oil Security Premiums

This section provides alternative estimates of the oil supply premium based upon the possibility of effects on oil price shocks and GDP impacts. These estimates include the values from the 2018 overview (Brown 2018) that are used in the analysis provided in our main report. Values from the 2018 study are shown for three sets of average estimates based upon the date of the studies used to calculate the average values: (a) older literature; (b) newer literature; and (c) combination of the older and newer literature. As noted below, Brown (2018) recommend use of the combined set of estimates.

1. Security Premiums Used in NHTSA/EPA PRIA

Table J-1 shows the values used by NHTSA/EPA, as included in the CAFE Model documentation and analysis files. To be consistent with other estimates from the literature, the values are changed from $/gallon to $/barrel, based upon a conversion of 42 gallons per barrel.

Table J-1. Changes in Expected Cost of Petroleum Price Shocks from Increased Oil Imports Consumption (2016$/barrel)

Year	2016$/barrel
2017	$8.13
2020	$8.34
2025	$9.04
2030	$9.60
2035	$10.35
2040	$10.35
2045	$10.35
2050	$10.35

Note: For ease of exposition table includes annual values at five year increments. Note that the actual analysis relies on annual-specific values for all relevant years as provided in the CAFE Model parameters file available on the NHTSA website. Values have been converted from barrels to gallons based on an assumed 42 gallons per barrel.
Source: CAFE Model analysis parameters file available on the NHTSA website.

The PRIA notes that these values are based upon those in the previous CAFE RIA (2012), with the dollars adjusted to 2016$. In reviewing the 2012 RIA it seems that this value originated from a 2012 study from Oakridge National Laboratory.[38] The PRIA notes that these values may significantly overstate the security premium based on changes since 2011 in petroleum and related fuel price and projections as well as in the U.S. dependency on imported oil.

2. Security Premium from 2018 Review Study

Table J-2 shows estimates of the security premium provided in the 2018 review article based upon three categorizations of the literature: (a) Old literature, defined as studies before 2010; (b) New literature, defined as studies after 2009[39]; and (c) Combined literature, including both the

[38] Paul N. Leiby, "Estimating the U.S. Oil Security Premium for the 2017-2025 Light -Duty Vehicle GHG/Fuel Economy Rule", Oak Ridge National Laboratory (ORNL), July 15, 2012.
[39] Studies from 2009 and 2010 were grouped into "old" or "new" literature based on the author's judgement. See Brown (2018), p. 174.

Old and New literature. The values represent the security premiums for imported oil and domestic oil. Note that the dollars have been changed from 2015$ in the original to 2016$ used in this study.

Table J-2. Changes in Expected Cost of Petroleum Price Shocks from Increased Oil Consumption (2016$/barrel)

Model	Consumption of Imported Oil	Consumption of Domestic Oil
PVL - O	$7.00	$5.42
PVL - N	$1.66	$1.26
PVL - C	$4.88	$3.74

Note: For ease of exposition table includes annual values at five-year increments. Note that the actual analysis relies on annual-specific values for all relevant years as provided in the CAFE Model parameters file available on the NHTSA website. Values have been converted from barrels to gallons based on an assumed 42 gallons per barrel.
Source: Table 9 from Brown (2018).

C. Results for Petroleum Externality Benefits under Alternative CAFE Standards

This section provides estimates of petroleum externality benefits under the three CAFE alternatives we consider, based upon the oil security premiums described above. Petroleum externality benefits are calculated by multiplying estimates of changes in consumption of imported and domestic oil by estimates of the respective oil security premiums.

1. Primary Results

Table J-3 summarizes estimates of changes in benefits associated with petroleum market externalities due the three alternative CAFE standards we consider. These values correspond to the ones included in the main report. These values are based upon the following information: (1) consumption of domestic and imported oil developed via the MOVES model; and (2) the oil security premiums developed in the 2018 review article; and (3) the values for the Combined studies since they are recommended "to better reflect the uncertainty about the response of world oil markets and the U.S. economy to world oil supply disruptions." (Brown 2018, p. 182).

Table J-3. Petroleum Market Externality Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Petroleum Market Externality Benefits	-$1.3	-$0.8	-$2.2	-$1.3	-$3.9	-$2.3

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.
Source: NERA/Trinity calculations as explained in text.

2. Sensitivity Cases

This section provides three sensitivity cases involving use of alternative values for the oil security premium.

a. NHTSA/EPA PRIA Oil Security Premiums

Table J-4 shows benefit estimates using the oil security premium values used by NHTSA/EPA in the PRIA.

Table J-4. Petroleum Market Benefits Relative to Augural Standards Baseline using NHTSA/EPA PRIA Estimates of Oil Price Shock Externalities (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Petroleum Market Externality Benefits	-$2.4	-$1.4	-$4.1	-$2.4	-$7.4	-$4.4

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.

Source: NERA/Trinity calculations as explained in text.

b. 2018 Review Article Older Studies

Table J-5 shows benefits estimates using the oil security premium values taken from the older studies in the 2018 review article.

Table J-5. Petroleum Market Externality Benefits Relative to Augural Standards Baseline using "Old Literature" Values from Brown (2018) (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Petroleum Market Externality Benefits	-$1.8	-$1.1	-$3.1	-$1.9	-$5.6	-$3.3

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.

Source: NERA/Trinity calculations as explained in text.

c. 2018 Review Article Newer Studies

Table J-6 shows benefits estimates using the oil security premium values taken from the new studies in the 2018 review article.

Table J-6. Petroleum Market Externality Benefits Relative to Augural Standards Baseline using "New Literature" Values from Brown (2018) (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Petroleum Market Externality Benefits	-$0.4	-$0.3	-$0.7	-$0.4	-$1.3	-$0.8

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.

Source: NERA/Trinity calculations as explained in text.

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Appendix K: Greenhouse Gas Emission Benefits

This appendix provides information on the data and methods developed by NERA to assess the benefits related to changes in greenhouse gas (GHG) emissions benefits due to the alternative CAFE standards. We focus this appendix on the monetary value of GHG emissions, which is based on the estimated future stream of damages from a one metric ton increase in GHG emissions. This discounted value is referred to as the Social Cost of Carbon (SCC), a value that varies over time. For our primary set of SCC values, we rely upon the domestic SCC values developed by EPA in the Regulatory Impact Analysis (RIA) for the Clean Power Plan (CPP) Review; these domestic values were used by NHTSA/EPA in the PRIA.[40] As a sensitivity case, we show results using the global SCC values that are reported by EPA in the CPP Review RIA.

A. Overview of Methodology to Develop Social Cost of Carbon Values

SCC values were first developed by the Interagency Working Group on Social Cost of Carbon (IWG) in 2010 (IWG 2010). The IWG issued technical updates in 2013 (IWG 2013), 2015 (IWG 2015) and 2016 (IWG 2016). The estimates developed by the IWG are based upon results from three integrated assessment models (IAMs)—referred to as PAGE, FUND, and DICE—using various assumptions regarding future parameters that affect damages, including income and population growth. The values developed by EPA in the CPP Review RIA rely upon results from the same three IAMs.

1. Use of Results from Integrated Assessment Models to Develop SCC Values by Discount Rate

IAMs are complex models of the global climate and economy that translate CO_2 emissions into changes in the climate system (most notably, temperature increases), and then translate these changes in the climate system into various types of economic damages, summarized by losses in gross domestic product (GDP). Since these models consider the damages over the atmospheric lifetime of a unit increase in CO_2 emissions (i.e., 1 metric ton), the results are sensitive to many factors such as the probability distribution for equilibrium climate sensitivity, socioeconomic, population, and emissions growth trajectories; and discount rate assumptions.

The PRIA provides a summary of the methodology used by EPA to develop SCC values. This methodology includes the following computational steps to determine a social cost of carbon estimate for a given year t:

1. Calculate the temperature effects and (consumption-equivalent) damages in each year from the baseline path of CO_2 emissions;
2. Adjust the model to reflect an additional unit of CO_2 emissions in year t;

[40] See NERA (2018) for information on alternative estimates of the social costs of carbon and effects on the PRIA net benefit estimates.

3. Recalculate the temperature effects and damages expected in all years beyond t resulting from this adjusted path of emissions, as in step 1;

4. Subtract the damages computed in step 1 from those in step 3 in each model period and discount the resulting path of marginal damages back to the year of the assumed unit change in CO_2 emissions (pp. 1106-1107).

For each discount rate, these four steps are repeated for each of the three IAMs with each of the five socio-economic and emissions trajectories. This results in 10 different distributions of annual SCC estimates for each of the three discount rates that are used by EPA in the CPP Review RIA (2.5%, 3% and 7%). These distributions are equally weighted and combined to produce a single set of annual SCC values for a given discount rate.

2. Use of Values Based on Domestic Rather than Global Damages

The values reported by NHTSA/EPA in the PRIA are domestic values, i.e., they reflect IAM estimates for domestic damages rather than global damages. Moreover, the values are reported for two of the three discount rates, 3% and 7%. The domestic values are obtained directly in the PAGE and FUND models; for the DICE model (which models only global damages), EPA approximates the domestic damages as 10 percent of the global values.

B. Social Cost of Carbon Values

This section provides the SCC values we used, including the domestic SCC values as well as the global values developed by EPA in the CPP Review RIA.

1. Domestic SCC Values

Table K-1 shows the domestic SCC values developed by EPA in the CPP Review RIA, using both 3% and 7% discount rates. As noted, these values were used NHTSA/EPA in the PRIA. We use these values as the basis for the estimates of GHG benefits in the main report (see Table 45).

Table K-1. EPA Domestic Social Costs of Carbon Values (2016$/metric ton)

	Discount Rate	
Year	**3%**	**7%**
2017	$6	$1
2020	$7	$1
2025	$7	$1
2030	$8	$1
2035	$9	$2
2040	$9	$2
2045	$10	$2
2050	$11	$2

Note: Values rounded to nearest whole dollar. For ease of exposition table includes annual values at five-year increments. Note that the actual analysis relies on annual-specific values for all relevant years as provided in the CAFE Model parameters file available on the NHTSA website.

Source: Table 8-24 from NHTSA/EPA PRIA; CAFE Model analysis parameters file available on the NHTSA website.

2. Global SCC Values

OMB Circular A-4 states that when an agency "evaluate[s] a regulation that is likely to have effects beyond the borders of the United States, these effects should be reported separately" (page 15 of OMB Circular A-4). The RIA for the CPP Review notes that this OMB guidance is relevant to the valuation of GHG emissions, since these pollutants contribute to damages around the world regardless of the location from which they are emitted (EPA 2017, p. 168).

We develop global SCC values based on information in the CPP Review RIA. Note that the CPP Review RIA does not provide a full list of their global SCC values for all years and discount rates. EPA does provide the following information on their global SCC results, which allows us to develop estimates of global SCC values for the years in our analysis (2017 to 2050).

- The domestic SCC estimates are approximately 14 percent of the global SCC estimates using a 3 percent discount rate;
- The domestic SCC estimates are approximately 19 percent of the global SCC estimates using a 7 percent discount rate;
- The average global SCC estimate across all the model runs for emissions occurring over 2020-2030 ranges from $44 to $53 per metric ton of CO_2 emissions (2011$) using a 3 percent discount rate (2011$); and
- The average global SCC estimate across all the model runs for emissions occurring over 2020-2030 ranges from $5 to $7 per metric ton of CO_2 emissions (in 2011 dollars) using a 7 percent discount rate.

Based on this information we developed a set of global SCC estimates based on discount rates of 3 percent, and 7 percent. These values are summarized in Table K-2.

Table K-2. Estimates of Global Social Costs of Carbon Values (2016$/metric ton)

	Discount Rate	
Year	3%	7%
2015	$44	$4
2020	$47	$5
2025	$51	$6
2030	$56	$7
2035	$61	$8
2040	$66	$10
2045	$71	$11
2050	$76	$13

Note: Values rounded to nearest whole dollar. For ease of exposition table includes annual values at five-year increments.
Source: EPA (2017) and NERA assumptions as explained in text; CAFE Model analysis parameters file available on the NHTSA website.

C. Results for Greenhouse Gas Emissions Benefits under Alternative CAFE Standards

This section provides estimates of the GHG benefits under the three CAFE alternatives we evaluate, based upon the SCC values described above, including the domestic SCC values (which are the basic estimates used in the main report) and the global SCC values (which represent a sensitivity case). The results include the GHG emissions impact of the alternative standards on both (a) tailpipe emissions developed using the MOVES model as summarized in Appendix F and (b) upstream emissions developed based on applying the upstream emissions factors used by NHTSA/EPA in the PRIA to our estimates of changes in fuel consumption as summarized in Figure 6.

1. Results Based on Domestic Social Cost of Carbon Values

Table K-3 provides our estimates of domestic CO_2 reduction benefits for each scenario relative to the augural standards baseline, based upon Trinity estimates of changes in upstream emissions. Note that these are same values reported in Table 45.

Table K-3. Domestic CO_2 Reduction Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
GHG Damage Reduction Benefits	-$1.6	-$0.2	-$2.9	-$0.3	-$7.1	-$0.7

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. GHG damage reduction benefits values include benefits associated CO_2, as well as other GHG pollutants, which have been converted to CO_{2eq}.

Source: NERA/Trinity calculations as explained in text.

2. Sensitivity Case Using Global SCC Values

Table K-4 provides our estimates of global CO_2 reduction benefits, which we calculate using the SCC values included in Table K-2, for each scenario relative to the augural standards baseline

Table K-4. Global CO_2 Reduction Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
GHG Damage Reduction Benefits	-$11.7	-$0.9	-$20.6	-$1.5	-$50.8	-$3.8

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. GHG damage reduction benefits values include benefits associated CO_2, as well as other GHG pollutants, which have been converted to CO_{2eq}.

Source: NERA/Trinity calculations as explained in text.

D. References

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Appendix L: Criteria Pollutant Emissions Benefits

This appendix provides information on the data and methods developed by NERA to assess the benefits due to changes in criteria pollutant benefits due to the alternative CAFE standards. We focus this appendix on the monetary value of three of the criteria pollutants—particulate matter ($PM_{2.5}$), nitrogen oxides (NO_x), and sulfur dioxide (SO_2)—based upon information provided in a February 2018 EPA Document entitled "Technical Support Document Estimating the Benefit per Ton of Reducing $PM_{2.5}$ Precursors from 17 Sectors" (EPA 2018).[41] This document provides estimates of the benefits per ton of reducing these three pollutants in 17 sectors, including on-road mobile sources and refineries, based upon their roles as precursors of $PM_{2.5}$. Note that the monetary values we develop exclude various welfare effects including: (a) effects other than the health effects of exposure to $PM_{2.5}$ from these three criteria pollutants; and (b) effects due to carbon monoxide (CO), though these emissions impacts are included in Chapter III.

To develop benefits estimates based upon the benefit-per-ton estimates, we rely upon Trinity's estimates of the changes in (a) tailpipe emissions due to the three CAFE alternatives as reflected in the MOVES results as summarized in Appendix F and (b) upstream emissions developed based on applying the upstream emissions factors used by NHTSA/EPA in the PRIA to our estimates of changes in fuel consumption due to the alternative standards as summarized in Figure 6.

A. Overview of Methodology to Develop Benefit-per-Ton Values

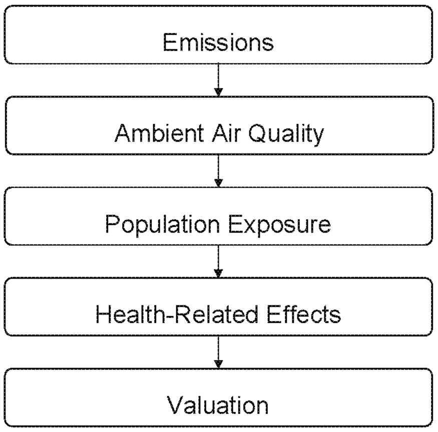
The benefit-per-ton method rests on the premise that the conceptually correct measure of the value of reducing a ton of pollutant is equal to the value of the reduced damages from reducing that ton (assuming no binding cap-and-trade program or other equivalent method for internalizing the damages from emissions). Potential damages can include effects on health, visibility, agriculture, and other effects.

1. Overview of Steps in Developing Benefit-per-Ton Values

The benefit-per-ton approach is illustrated in Figure L-1 as a series of steps involving different modeling and estimation procedures.

[41] We note that NERA has not evaluated the underlying studies behind the dollar benefit values in the February 2018 EPA $PM_{2.5}$ Technical Support Document and thus our use of the values does not constitute confirmation of the validity or accuracy of the benefit estimates.

Figure L-1. Steps in Estimating Environmental Benefits from Reduction in Criteria Pollutants



The following are brief overviews of these steps.

- *Effects of emissions on air quality*. The criteria air emissions contribute to ambient concentrations of various criteria pollutants, notably $PM_{2.5}$ and ozone. Ambient $PM_{2.5}$ concentrations arise from $PM_{2.5}$ particles that are emitted directly and from small-diameter particulates that are formed by chemical reactions in the air involving NO_x and SO_2. Ozone is formed by complicated atmospheric photochemical reactions involving NO_x, VOC, and sunlight. The source of emissions (e.g., stationary versus mobile source) can have a significant effect on pollutant dispersion and thus on the effects on air pollutant concentrations.
- *Effects of air quality on population exposure*. The benefits associated with decreases in ambient concentrations of $PM_{2.5}$ and ozone depend on the number of people exposed to the increased concentrations. Decreases in $PM_{2.5}$ and ozone concentrations will have larger health benefits in populous areas than in rural areas. Other effects, such as possible reductions in agricultural yields, also depend on (non-human) exposure.
- *Effects of population exposure on various adverse effects*. The relationship between increased exposure and increased health and welfare effects is a crucial element of the benefit-per-ton approach to assessing environmental costs. For health effects, such relationships typically are measured with concentration-response ("C-R") functions, which are based upon statistical studies from the epidemiology literature.[42] "C-R functions are equations that relate the change in the number of individuals in a population exhibiting a 'response' … to a change in pollutant concentration experienced by that population" (U.S. EPA 1999, p. 52). The "responses" described by C-R functions are often referred to as health endpoints. C-R functions translate changes in the numbers of people exposed to

[42] In the case of non-health effects (such as effects on agricultural yield), these relationships are typically called "exposure-response" functions.

various ambient pollutant concentrations into changes in health effects. U.S. EPA notes that "epidemiological studies, by design, are unable to definitively prove a causal relationship between an exposure and a given health effect; they can only identify associations or correlations between exposure and the health outcome" (U.S. EPA 1999, p. D-7). Nonetheless, such studies generally provide the primary basis for developing C-R functions.

- *Valuation of health and other welfare changes.* Once increased incidences of health effects (or other effects, to the extent that they are considered) are determined, the dollar values of those effects must be estimated to generate estimated benefit values for a reduction in direct air emissions. Over the past several decades, economists and other researchers have devised various methods for estimating how much people are willing to pay to reduce risks to health, including the risk of premature mortality. Some of the methods rely upon the implicit tradeoffs that individuals make in various decisions; for example, statistical models have been used to estimate the increased wages that workers demand in riskier occupations. Other methods rely upon direct surveys of representative individuals.

2. Limitations of Using National Benefits per Ton Values

The benefit-per-ton estimates developed in the documents used in this study are national average estimates. But as the overview of the steps involved in their estimation makes clear, the actual benefits are highly dependent upon location. Benefits can vary greatly depending on the regional meteorology, characteristics of emissions sources, and susceptibility of local populations to "adverse health outcomes" (Fann et al. 2009, p. 170). This feature contrasts to the case of GHG emissions, which have the same effects regardless of where they are emitted. Thus, the estimates of changes in benefits due to changes in emissions of criteria pollutants that are provided in this study should be viewed as speculative for various reasons, including the fact that they do not account for the locations of the changes in emissions due to the alternative CAFE standards.

B. Benefit-per-Ton Values

This section provides alternative benefit-per-ton values, including the values based upon the 2018 EPA $PM_{2.5}$ Technical Support Document that are the primary values used in this study. These values are shown for three sectors: (a) on-road mobile sources; (b) area sources; and (c) refinery. We begin with a table showing values used by NHTSA/EPA in the PRIA and by EPA in the 2012 RIA. The values used by NHTSA/EPA in the PRIA are used in sensitivity analyses provided at the end of this appendix.

1. Benefit-per-Ton Values in NHTSA/EPA PRIA

NHTSA/EPA notes in the PRIA (2018) that they use benefit-per-ton values from the 2012 RIA "Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards" (hereafter, "2012 RIA") adjusted to 2016 dollars. Table L-1 shows these benefit-per-ton values. These benefit-per-ton values are based on human health benefits associated with reductions in $PM_{2.5}$ exposure—that is, they do not estimate health benefits relating to ozone precursors, or those directly from NO_x or SO_2 (which are included as precursors to $PM_{2.5}$) (EPA 2012, p. 6-99). According to EPA, these estimates are derived from health impact functions used in the 2006 PM NAAQS RIA.[43]

Table L-1. PRIA Benefit-per-Ton Values (2016$/metric ton)

Pollutant	2016$/mt
Volatile Organic Compounds (VOCs)	$2,000
Nitrogen Oxides	$8,200
Particulate Matter	$371,100
Sulfur Dioxide	$48,000

Source: CAFE Model analysis parameters file available on the NHTSA website.

2. Benefit-per-Ton Values in 2012 EPA RIA

The 2012 RIA (in Table 6.3-14 of the 2012 RIA provides benefit-per-ton numbers as a range, with values differing by emissions source (i.e., mobile-source and stationary), year, discount rate, and epidemiology study (i.e., Pope et al., 2002 and Laden et al., 2006). Table L-2 and Table L-3 show the values, with results from the two epidemiology studies weighted equally (as EPA indicates is appropriate). Note that EPA does not provide separate SO_2 values by emissions source (i.e., provides a single set of values for both mobile-source and stationary). EPA also does not include estimates of the benefit-per-ton value for VOCs.

Table L-2. 2012 EPA RIA Benefit-per-Ton Values for Mobile-Source Emissions (2016$/metric ton)

	3% Discount Rate			7% Discount Rate		
Year	$PM_{2.5}$	SO_2	NO_X	$PM_{2.5}$	SO_2	NO_X
2017	550,000	59,000	10,000	500,000	53,000	8,900
2020	580,000	62,000	11,000	530,000	56,000	9,400
2025	640,000	68,000	12,000	580,000	61,000	11,000
2030	700,000	73,000	13,000	630,000	66,000	12,000
2035	770,000	79,000	14,000	690,000	71,000	13,000
2040	850,000	85,000	15,000	750,000	77,000	14,000
2045	920,000	92,000	17,000	810,000	83,000	15,000
2050	1,000,000	98,000	18,000	870,000	89,000	16,000

Note: Values in 2016$/metric ton. Dollar year conversions based on implicit GDP deflator information from BEA.

Source: EPA RIA (2012); NERA calculations as explained in text; BEA (2018).

[43] The 2006 PM NAAQS RIA uses premature mortality related coefficients from epidemiology studies that examine two major population cohorts: the American Cancer Society cohort (Pope et al., 2002) and the Harvard Six Cities cohort (Laden et al., 2006). (EPA 2012, p. 6-103)

Table L-3. 2012 EPA RIA Benefit-per-Ton Values for Stationary-Source Emissions (2016$/metric ton)

	3% Discount Rate			7% Discount Rate		
Year	$PM_{2.5}$	SO_2	NO_X	$PM_{2.5}$	SO_2	NO_X
2017	450,000	59,000	9,600	410,000	53,000	8,900
2020	480,000	62,000	10,000	440,000	56,000	9,300
2025	520,000	68,000	11,000	470,000	61,000	10,000
2030	560,000	73,000	12,000	510,000	66,000	11,000
2035	600,000	79,000	14,000	550,000	71,000	12,000
2040	650,000	85,000	15,000	590,000	77,000	13,000
2045	700,000	92,000	16,000	630,000	83,000	14,000
2050	740,000	98,000	17,000	670,000	89,000	15,000

Note: Values in 2016$/metric ton. Dollar year conversions based on implicit GDP deflator information from BEA.

Source: EPA RIA (2012); NERA calculations as explained in text; BEA (2018).

3. Benefit-per-Ton Values in EPA (2018)

Table L-4 and Table L-5 shows estimates of the benefits-per-ton values for the three pollutants included in EPA (2018) over time. The values are based upon EPA's 2017 version of its environmental Benefits Mapping and Analysis Program—Community Edition (BenMAP-CE) tool. As discussed below, EPA TSD (2018) includes a discussion of the limitations and uncertainties associated with application of these estimates. The tables show results for tailpipe emissions and upstream emissions for two discount rates. Benefit-per-ton estimates for each pollutant and discount rate were developed based on the average benefit-per-ton value across the two epidemiological studies reported in EPA (2018).

For tailpipe emissions, we rely on the values reported in the EPA $PM_{2.5}$ TSD (2018) for the "on-road mobile sources" sector. For upstream emissions, whose activities span multiple sectors, we use a weighted-average based on the "On-Road Mobile Sources" (25%), "Aircraft, Locomotives and Marine Vessels[44]" (25%), and "Refineries" (50%) sectors. Based on our review of the upstream emissions factors used by NHTSA, we conclude that a combination of these sectors would most accurately capture the underlying fuel development and transportation, distribution, and storage activities. Note that the EPA (2018) includes values for 2016, 2020, 2025, and 2030 only. We interpolate linearly between each chronological pair of years (e.g., 2020 and 2025) to develop appropriate estimates for intermediate years. For years beyond 2030, we extrapolate based on the linear trend from 2025 to 2030. Note that EPA (2018) does not include estimates of the benefit-per-ton value for VOCs.

[44] EPA (2018) notes that due to an emissions processing error, the current values for "aircraft, locomotives, and marine vessels" sector omit aircraft omissions (p. 5)

Table L-4. EPA (2018) Benefit-per-Ton Values for Tailpipe Emissions (2016$/metric ton)

	3% Discount Rate			7% Discount Rate		
Year	**$PM_{2.5}$**	**SO_2**	**NO_X**	**$PM_{2.5}$**	**SO_2**	**NO_X**
2017	670,000	36,000	14,000	600,000	32,000	13,000
2020	690,000	38,000	15,000	620,000	34,000	13,000
2025	740,000	41,000	15,000	680,000	38,000	14,000
2030	810,000	47,000	17,000	730,000	41,000	15,000
2035	880,000	52,000	18,000	790,000	45,000	17,000
2040	950,000	57,000	19,000	840,000	49,000	18,000
2045	1,000,000	62,000	21,000	900,000	52,000	19,000
2050	1,100,000	67,000	22,000	960,000	56,000	21,000

Note: Values in 2016$/metric ton. Dollar year conversions based on implicit GDP deflator information from BEA. Tailpipe emissions benefit-per-ton values based on the "On-Road Mobile-Source" values from EPA (2018). For ease of exposition, values rounded to two significant figures.

Source: EPA Technical Support Document (EPA 2018); BEA (2018); NERA calculations as explained in text.

Table L-5. EPA (2018) Benefit-per-Ton Values for Upstream Emissions (2016$/metric ton)

	3% Discount Rate			7% Discount Rate		
Year	**$PM_{2.5}$**	**SO_2**	**NO_X**	**$PM_{2.5}$**	**SO_2**	**NO_X**
2017	570,000	110,000	13,000	510,000	97,000	12,000
2020	590,000	110,000	13,000	530,000	100,000	12,000
2025	640,000	120,000	14,000	580,000	110,000	13,000
2030	690,000	140,000	16,000	620,000	120,000	14,000
2035	750,000	150,000	17,000	670,000	140,000	16,000
2040	810,000	160,000	18,000	720,000	150,000	17,000
2045	860,000	180,000	20,000	770,000	160,000	18,000
2050	920,000	190,000	21,000	820,000	170,000	20,000

Note: Values in 2016$/metric ton. Dollar year conversions based on implicit GDP deflator information from BEA. Upstream emissions benefit-per-ton values based on a weighted-average of the "On-Road Mobile Sources" (25%), "Aircraft, Locomotives, and Marine Vessels" (25%), and "Refineries" (50%) sectors from EPA (2018). For ease of exposition, values rounded to two significant figures.

Source: EPA Technical Support Document (EPA 2018); BEA (2018); NERA calculations as explained in text.

The benefit-per-ton values from EPA's 2018 $PM_{2.5}$ TSD differ from those used by NHTSA in the PRIA along several dimensions.

1. *More recent demographic data*. The values included in EPA (2018) are based on the latest (2017) version of EPA's environmental BenMAP-CE.

2. *Updated epidemiology studies*. EPA (2018) incorporates updated morbidity and mortality studies, i.e., Krewski et al. (2009) and Lepeule et al. (2012).

3. *Discount rates*. EPA (2018) includes separate valuations estimates for 3 percent and 7 percent discount rates. The NHTSA/EPA PRIA valuation parameters do not differ by discount rate.

4. *Tailpipe vs Upstream*. EPA (2018) includes separate valuations estimates for emissions in different sectors including three sectors that seem most relevant for the CAFE analysis (on-road mobile, area, and refinery).

5. *Annual values*. EPA (2018) provides annual benefit-per-estimates for the relevant pollutants and discount rates. The NHTSA/EPA PRIA benefit-per-ton values do not vary by year.

As noted, we have not developed independent assessments of the validity of the information that lies behind the benefit-per-ton values included in EPA (2018) and the BenMAP-CE tool.

C. Results for Criteria pollutant Benefits under Alternative CAFE Standards

This section provides estimates of criteria pollutant benefits under the three CAFE alternatives we consider, based upon the benefit-per-ton values described above. Emissions reduction benefits are calculated by multiplying estimates of changes in emissions by estimates of the respective benefit-per-ton values. In calculating the primary benefits estimates, we rely on (1) tailpipe emissions developed via the MOVES model; (2) upstream emissions based on the upstream factors used by NHTSA/EPA in the PRIA developed via the GREET model; and (3) benefit-per-ton values developed in EPA (2018). Note that since EPA (2018) does not include benefit-per-ton estimates for VOCs, we develop monetary estimates of the criteria pollutant reduction benefits for VOCs based on the value used in the PRIA as reported in Table L-1. As a sensitivity case, we use the benefit-per-ton values used in the PRIA.

1. Primary Results

Table L-6 summarizes estimates of changes in benefits associated with criteria pollutant reductions due the three alternative CAFE standards we consider. These values correspond to the ones included in the main report.

Table L-6. Criteria Pollutant Emissions Reductions Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	**7%**	**3%**	**7%**	**3%**	**7%**
NO_x Damage Reduction Benefits	$0.0	$0.0	$0.1	$0.1	$0.0	$0.0
VOC Damage Reduction Benefits	$0.0	$0.0	-$0.1	$0.0	-$0.1	-$0.1
$PM_{2.5}$ Damage Reduction Benefits	-$0.4	-$0.2	-$0.8	-$0.5	-$1.7	-$1.0
SO_2 Damage Reduction Benefits	-$2.0	-$1.2	-$3.4	-$2.0	-$6.1	-$3.6
Total	**-$2.4**	**-$1.4**	**-$4.2**	**-$2.5**	**-$8.0**	**-$4.7**

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. Values may not sum to totals due to rounding.

Source: NERA/Trinity calculations as explained in text.

2. Sensitivity Case using NHTSA/EPA PRIA Benefit-per-Ton Values

Table L-7 shows benefit estimates using the benefit-per-ton values used by NHTSA/EPA in the PRIA as summarized in Table L-1 rather than the benefit-per-ton values we rely on from EPA (2018) as summarized in Table L-4 and Table L-5.

Table L-7. Criteria Pollutant Emissions Reductions Benefits Relative to Augural Standards Baseline using NHTSA/EPA PRIA Benefit-per-Ton Values (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
NO_x Damage Reduction Benefits	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
VOC Damage Reduction Benefits	$0.0	$0.0	-$0.1	$0.0	-$0.1	-$0.1
$PM_{2.5}$ Damage Reduction Benefits	-$0.3	-$0.1	-$0.5	-$0.3	-$1.0	-$0.6
SO_2 Damage Reduction Benefits	-$0.7	-$0.4	-$1.2	-$0.7	-$2.1	-$1.3
Total	**-$1.0**	**-$0.6**	**-$1.7**	**-$0.9**	**-$3.2**	**-$1.9**

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. Values may not sum to totals due to rounding.

Source: NERA/Trinity calculations as explained in text.

3. Limitations and Uncertainties

EPA (2018, pp. 25-27) discusses the limitations and uncertainties of the national benefit-per-ton values it reports. The following is a summary of the issues raised.

- *Data sources*. "The analysis includes many data sources as inputs, including emissions inventories, air quality data from models (with their associated parameters and inputs) population data, health estimates from epidemiology studies, and economic data for monetizing benefits. Each of these inputs may be uncertain and would affect the benefits estimate. When the uncertainties from each stage of the analysis are compounded, small uncertainties can have large effects on the total quantified benefits."

- *Equality of potency of all fine particles.* "In this analysis we assume that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because $PM_{2.5}$ produced via transported precursors emitted from EGUs may differ significantly from direct $PM_{2.5}$ released from other industrial sources. However, the scientific evidence is not yet sufficient to allow differentiation of effect estimates by particle type.

- *Linear down to lowest air quality level.* "We also assume that the health impact function for fine particles is linear down to the lowest air quality levels modeled in this analysis. Thus the estimates include health benefits from reducing fine particles in areas with varied concentrations of $PM_{2.5}$, including regions that are in attainment with fine particle standard."

- *Geographic patterns*. "It is also important to note that the monetized benefit per ton estimates used here reflect specific geographic patterns of emissions and specific air quality benefit modeling assumptions. Great care should be taken in applying these estimates to emission reductions occurring in any specific location, as these are all based on national emission reduction assumptions and therefore represent an average benefit per ton over the entire United States. The benefit per ton for emission reductions in specific locations may be very different from the estimates presented here."

- *Combinations of reductions*. "In addition, estimates do not capture important differences in marginal benefit per ton that may exist due to different combinations of reductions (i.e., all other sectors are held constant) or nonlinearities within a particular pollutant (e.g., non-zero second derivatives with respect to emissions)."

D. References

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NERA Economic Consulting
11th Floor, 200 Clarendon Street
Boston, Massachusetts 02116
Tel: 1 (617) 927-4500
www.nera.com

Trinity Consultants
3301 C Street, Suite 400
Sacramento, CA 95816
Tel: + 1 916 444-6666
www.trinityconsultants.com

Message

From: Harrison, David [David.Harrison@NERA.com]
Sent: 11/30/2018 3:14:51 PM
To: Charmley, William [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=fb1828fb00af42ffb68b9e0a71626d95-Charmley, William]
CC: Chris Nevers [CNevers@autoalliance.org]
Subject: RE: Question on the NERA study

Hi Bill,

Good to hear from you. The gasoline price projections we used are from AEO 2017, based upon the information in the CAFE model.

Please give my best to others in Ann Arbor.

Best,

== Dave

David Harrison, Ph.D., Managing Director
NERA
ECONOMIC CONSULTING
Tel: +1 617 927 4512
david.harrison@nera.com

From: Charmley, William <charmley.william@epa.gov>
Sent: Thursday, November 29, 2018 4:36 PM
To: Harrison, David <David.Harrison@NERA.com>
Cc: Chris Nevers <CNevers@autoalliance.org>
Subject: Question on the NERA study

Dear David –

I hope all is going well with you and your colleagues out in Cambridge.

My staff were reviewing with me today the NERA report conducted for the Auto Alliance "Evaluation of Alternative Passenger Car and Light Truck Corporate Average Fuel Economy (CAFE) Standards for Model Years 2021-2026" which was submitted by the Alliance as part of their comments on the recent DOT/EPA proposal for fuel economy and GHG standards for light-duty vehicles.

At this point I we have one clarifying question that I am hoping you can answer for us, and that it, what gasoline fuel price projections did NERA use for the NERA analysis? In particular, in the Table 48 Net Benefits projections on page 61, which fuel price projection forecast was used? This is the same information presented in Table ES-3 in the Executive Summary.

We see discussion in the report of EIA's AEO 2017 projections, and also the 2018 IHS Markit Retail Gasoline Price Forecast. Were one of these used in the NERA modeling to detailed in the report, and in particular the analysis presented in the Tables ES-3 and Table 48?

Thank you for your help on this.

Best regards,
Bill

Bill Charmley
Director
Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

National Vehicle and Fuel Emissions Laboratory
2000 Traverwood Drive
Ann Arbor, MI 48105

desk ph. 734-214-4466
cell ph. 734-545-0333
e-mail: charmley.william@epa.gov

Message

From: Harrison, David [David.Harrison@NERA.com]
Sent: 12/17/2018 8:39:02 PM
To: Charmley, William [/o=ExchangeLabs/ou=Exchange Administrative Group (FYDIBOHF23SPDLT)/cn=Recipients/cn=fb1828fb00af42ffb68b9e0a71626d95-Charmley, William]
CC: CNevers@autoalliance.org
Subject: RE: A second question on the NERA study

Hi Bill,

Thanks for your note—glad to provide additional explanation of the sentence on p. 55 of the NERA report ("Our methodology for estimating the benefit consumers receive from the improved fuel efficiency includes changes in consumers' valuation of prospective fuel savings from improvements."). Here are two bullet points providing additional explanation and background.

- *Explanation on p. 54 of the NERA report*. Section 1.a on the prior page (p. 54) provides the following explanation
  - "The first component of our estimate of consumers' benefit of fuel economy improvements is the consumers' own valuation of expected fuel savings. The CAFE Model provides estimates of the changes in fuel efficiency that vehicles will achieve towards compliance in each CAFE standard alternative. We estimate consumers' willingness-to-pay for a unit decrease in fuel costs per mile in the New Vehicle Market Model . . . We combine this valuation from the new Vehicle Market Model with the CAFE Model results on changes in fuel economy to develop dollar values of the changes in benefits to consumers of the fuel economy changes under the three CAFE standard alternatives." NERA Report, p. 54
- *Criteria for evaluating societal benefits*. The use of "willingness to pay" to measure societal benefits is consistent with EPA *Guidelines for Preparing Economic Analyses* (December 17, 2010, updated May 2014).
  - As noted on p. 47 of our report, our methodology is based on these EPA *Guidelines*.
  - The EPA *Guidelines* are explicit in noting that the calculation of societal benefits of a policy should be based on consumers' willingness to pay for potential impacts. Here is a succinct quote from p. 7-6 of the *Guidelines* that summarizes the step in which potential effects of a policy (in this context, improvements in fuel economy from the NHTSA standards) are valued in dollar terms. "The next step is to estimate willingness to pay (WTP) of all affected individuals for the quantified benefits in each benefit category, and then to aggregate these to estimate the total social benefits of each policy option." EPA *Guidelines*, p. 7-6.

Please let me know if there are any other questions on this point.

Thanks,

== Dave

David Harrison, Ph.D., Managing Director
NERA
ECONOMIC CONSULTING
Tel: +1 617 927 4512
david.harrison@nera.com

From: Charmley, William <charmley.william@epa.gov>
Sent: Friday, December 14, 2018 12:59 PM
To: Harrison, David <David.Harrison@NERA.com>

Cc: CNevers@autoalliance.org
Subject: A second question on the NERA study

David,

My staff and I had another question regarding the NERA study on the SAFE NPRM done for the Auto Alliance.

We are trying to understand why the NERA study estimated in the net societal benefits for fuel savings is much lower then what was projected in the Notice of Proposed Rulemaking.

In the NPRM, NHTSA estimated the pre-tax fuel savings for society for the proposal to be over $100 billion. In the NERA report, the reported "Valuation of Fuel Cost Savings" is $51.3 billion with a 3% discount rate and $38.0 billion with a 7% discount rate (shown in Table 40 on page 55, which I copied into this email). Those values include the taxes, so the "pre-tax" values would be lower than these values.

On page 55 of the NERA report, under Section B., there is the following statement:

> *"Our methodology for estimating the benefit consumers receive from the improved fuel efficiency includes changes in consumers' valuation of prospective fuel savings from improvements."*

We understand that in the context of a consumer choice model, it would be appropriate to consider what the consumers valuation of fuel savings are. But in the Net Societal Benefits, we would have thought that all of the pre-tax fuel savings would be included.

Can you let us know how NERA looked at this issue, and are we interpreting this correctly – that in the Net Societal Benefits, the NERA analysis does not include all of the pre-tax fuel savings, but something less than all of it?

Thanks
Bill

Table 40. Fuel Economy Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Valuation of Fuel Cost Savings	-$16.7	-$12.4	-$28.9	-$21.3	-$51.3	-$38.0
Rebound Mobility Benefit	-$9.7	-$5.8	-$17.4	-$10.3	-$31.0	-$18.5
Refueling Time Benefit	-$1.6	-$0.9	-$2.7	-$1.6	-$4.9	-$2.9
Benefits of Fuel Economy Changes	**-$28.0**	**-$19.1**	**-$49.0**	**-$33.3**	**-$87.2**	**-$59.5**

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.

Source: NERA/Trinity calculations as explained in text.

From: Charmley, William
Sent: Friday, November 30, 2018 3:55 PM
To: Harrison, David <David.Harrison@NERA.com>
Subject: RE: Question on the NERA study

David –

Thanks for getting back to me, I appreciate it.

Best regards,
Bill

From: Harrison, David <David.Harrison@NERA.com>
Sent: Friday, November 30, 2018 10:15 AM
To: Charmley, William <charmley.william@epa.gov>
Cc: Chris Nevers <CNevers@autoalliance.org>
Subject: RE: Question on the NERA study

Hi Bill,

Good to hear from you. The gasoline price projections we used are from AEO 2017, based upon the information in the CAFE model.

Please give my best to others in Ann Arbor.

Best,

== Dave

David Harrison, Ph.D., Managing Director
NERA

ECONOMIC CONSULTING
Tel: +1 617 927 4512
david.harrison@nera.com

From: Charmley, William <charmley.william@epa.gov>
Sent: Thursday, November 29, 2018 4:36 PM
To: Harrison, David <David.Harrison@NERA.com>
Cc: Chris Nevers <CNevers@autoalliance.org>
Subject: Question on the NERA study

Dear David –

I hope all is going well with you and your colleagues out in Cambridge.

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We see discussion in the report of EIA's AEO 2017 projections, and also the 2018 IHS Markit Retail Gasoline Price Forecast. Were one of these used in the NERA modeling to detailed in the report, and in particular the analysis presented in the Tables ES-3 and Table 48?

Thank you for your help on this.

Best regards,
Bill

Bill Charmley
Director
Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

National Vehicle and Fuel Emissions Laboratory
2000 Traverwood Drive
Ann Arbor, MI 48105

desk ph. 734-214-4466
cell ph. 734-545-0333
e-mail: charmley.william@epa.gov

Message

From: Charmley, William [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=FB1828FB00AF42FFB68B9E0A71626D95-CHARMLEY, WILLIAM]
Sent: 11/30/2018 8:54:39 PM
To: Harrison, David [David.Harrison@NERA.com]
Subject: RE: Question on the NERA study

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desk ph. 734-214-4466
cell ph. 734-545-0333
e-mail: charmley.william@epa.gov

Message

From:	Charmley, William [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=FB1828FB00AF42FFB68B9E0A71626D95-CHARMLEY, WILLIAM]
Sent:	11/29/2018 9:35:53 PM
To:	David Harrison (david.harrison@nera.com) [david.harrison@nera.com]
CC:	Chris Nevers [CNevers@autoalliance.org]
Subject:	Question on the NERA study
Attachments:	Attachment 1 NERA Evaluation of Alternative Passenger Car and Light Duty Truck CAFE Standards.pdf

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desk ph. 734-214-4466
cell ph. 734-545-0333
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EPA-HQ-2019-005904

Evaluation of Alternative Passenger Car and Light Truck Corporate Average Fuel Economy (CAFE) Standards for Model Years 2021-2026

Prepared for the Alliance of Automobile Manufacturers

October 26, 2018

NERA
ECONOMIC CONSULTING
Trinity
Consultants

ED_002668_00000008-00001

Project Team

NERA Economic Consulting
David Harrison, Ph.D., Project Director
Andrew Busey
Eli Shakun
Katya Dajani
Charles Kuchenbrod

Trinity Consultants
James Lyons, Project Director
Thomas Carlson
Jonathan Snoeberger

Project Directors

Dr. David Harrison is a Managing Director and co-chair of NERA's global environmental economics practice. He has been active in the development and assessment of climate change and other major energy and environmental policies around the world as a consultant to numerous private and public groups. Before joining NERA, Dr. Harrison was an Associate Professor at Harvard's Kennedy School of Government and on the senior staff at the President's Council of Economic Advisors. He received a Ph.D. in economics from Harvard University, a M.Sc. in economics from the London School of Economics and a B.A. in economics from Harvard College.

Mr. James Lyons is a Principal Consultant at Trinity Consultants, Inc. He has extensive experience assessing the benefits, costs and cost-effectiveness of new vehicle emission standards for criteria pollutants, greenhouse gases, and fuel economy. Mr. Lyons was previously a Senior Partner at Sierra Research, Inc., and he began his career at the California Air Resources Board.

NERA Economic Consulting
11th Floor, 200 Clarendon Street
Boston, Massachusetts 02116
Tel: +1 617 927 4500
www.nera.com

Trinity Consultants
3301 C Street, Suite 400
Sacramento, CA 95816
Tel: + 1 916 444-6666
www.trinityconsultants.com

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Executive Summary

This report evaluates the effects of alternative Corporate Average Fuel Economy (CAFE) standards for passenger cars and light trucks (collectively "vehicles") for model year (MY) 2021 to MY 2026, developing results for three of the eight alternatives that were evaluated recently by the National Highway Traffic and Safety Administration (NHTSA) and the U.S. Environmental Protection Agency (EPA).[1] The evaluations are based upon a suite of models including ones developed by government agencies as well as ones developed by NERA Economic Consulting (NERA) and Trinity Consultants (Trinity). Our evaluations include estimates of the market impacts of alternative CAFE standards, including effects on new motor vehicle sales, on scrappage rates for existing vehicles, and on vehicle miles traveled (VMT). We use estimates of these market effects combined with other information to develop estimates of the social costs and social benefits of alternative CAFE standards, with resulting estimates of the net benefits for each of the alternatives.

A. Background

1. Modeling Framework

The modeling framework we use allows us to estimate the impacts of alternative CAFE standards on the motor vehicle fleet—including changes in new vehicle sales and changes in the scrappage of existing vehicles—as well as on VMT over the analysis period, which is from 2017 to 2050. Results are developed for light-duty vehicles for model years through MY 2029.[2] Figure ES-1 provides an overview of the framework, showing the models used and their interactions.

[1] The three alternatives we evaluate bracket the stringency range of CAFE standards evaluated by NHTSA and EPA. Note that NHTSA and EPA also evaluated standards for carbon dioxide (CO_2) emissions for the same model years. We estimate effects of the alternative CAFE standards and do not develop separate estimates for alternative CO_2 standards. Since the two sets of standards are harmonized, however, our comparative results for the alternative CAFE standards should apply to the equivalent CO_2 standards (although the specific estimates would differ).

[2] The analyses developed by NHTSA and EPA provide results of alternative MY 2021-MY 2026 standards for model years beyond MY 2026; following their analyses, we present results for changes through MY 2029.

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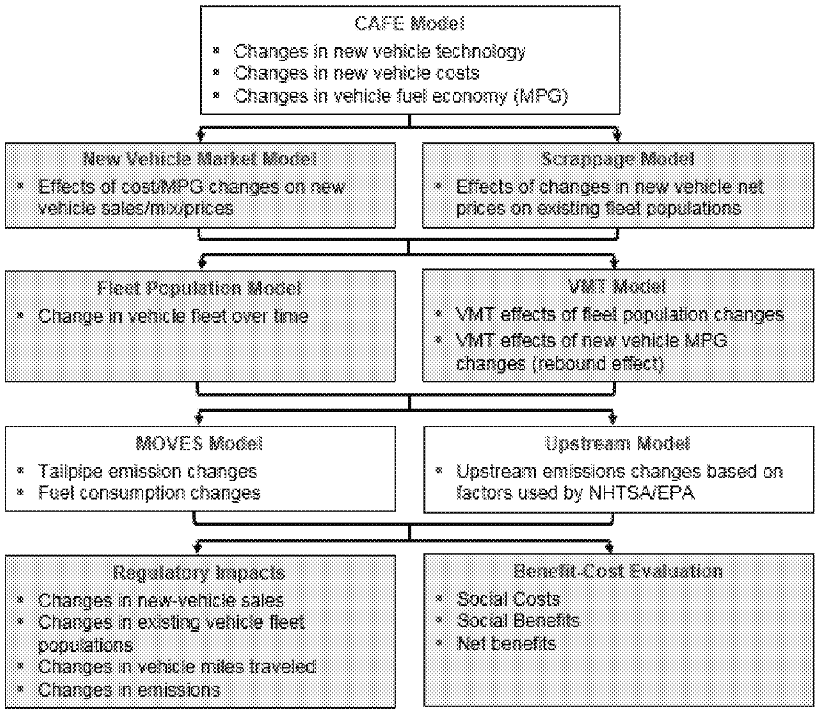
Figure ES-1. Model Structure



The following are brief overviews of these models.

- *CAFE Model.* The CAFE Model, developed by the Department of Transportation (DOT) and implemented by Trinity, provides detailed information on the light-duty vehicle fleet, consisting of detailed motor vehicle model/configurations for MY 2016 and projections for model years after 2016. Trinity uses the CAFE Model to estimate the effects of the three CAFE alternatives on motor vehicle costs and fuel economy for the detailed vehicle categories included in the CAFE Model.

- *New Vehicle Market Model.* The New Vehicle Market Model, developed by NERA, provides estimates of the effects of the regulatory alternatives on new vehicle prices and sales, based upon the compliance costs and fuel economy changes predicted in the CAFE Model. The estimated net changes in new vehicle prices reflect the costs to comply with the CAFE standards minus the value that new vehicle purchasers place on the changes in fuel economy, values that are developed as part of the New Vehicle Market Model.

- *Scrappage Model.* The Scrappage Model, developed by NERA, provides estimates of the changes in scrappage of existing vehicles (by vehicle age) due to the changes in new vehicle net prices.

- *Fleet Population Model.* The Fleet Population Model, developed by NERA and Trinity, keeps track of changes in the light-duty vehicle fleet over the analysis period (2017-2050), including information on the numbers of vehicles of different ages in each calendar year. Thus, for example, the fleet population model provides information on the number of passenger cars in 2030 in different age groups (e.g., new, 1-year old, 2-year old, etc.).

- *VMT Model.* This model, developed by NERA and Trinity, includes the effects of changes in VMT due to the alternative CAFE standards, including changes due to changes in the age profile of the fleet (reflecting lower VMT from older vehicles) as well as changes due to the well-recognized "rebound effect," i.e., the effect of changes in fuel efficiency on the cost per mile of driving and thus (via a price/demand effect) on the number of miles driven.
- *MOVES Model.* The MOVES Model, developed by EPA and implemented by Trinity, provides baseline information on the motor vehicle fleet and VMT and related values for emissions. Trinity uses MOVES to develop estimates of changes in vehicle tailpipe emissions due to the three alternative CAFE standards, accounting for changes in the age of the fleet as well as changes in VMT. The model includes results for greenhouse gas emissions, as well as emissions for five criteria pollutants.
- *Upstream Model.* The MOVES Model does not include estimates of changes in upstream emissions (e.g., refinery emissions due to changes in gasoline production). An Upstream Model is developed based on the upstream emissions factors used by NHTSA/EPA in the PRIA, which are based on the GREET Model developed by Argonne National Laboratory.

The figure does not show the many other parameters used in this study to develop estimates of social costs and social benefits of alternative CAFE standards, many of which are based upon information developed by NHTSA and EPA; information on these parameters is provided in the body of the report and in appendices.

2. Alternative CAFE Standards Evaluated

In the Preliminary Regulatory Impact Analysis (PRIA), NHTSA and EPA evaluated eight alternatives, all relative to the current set of standards (which is the "no action" alternative). This no action alternative assumes that the MY 2021 standards remain in place, that the MY 2022-2025 augural CAFE standards are finalized and that MY 2026 standards are set at MY 2025 levels.[3] For ease of exposition, we refer to the MY 2021 to MY 2026 standards in this baseline scenario as the "augural standards baseline." We evaluated three of these eight standards, as summarized in Table ES-1. The three alternatives we evaluated correspond to Alternative 1, Alternative 5, and Alternative 8 in the NHTSA/EPA PRIA. The alternatives are numbered in terms of stringency, so that Alternative 1 is the least stringent and Alternative 8 is the most stringent alternative (other than the augural standards baseline, which is the most stringent). The three CAFE alternatives evaluated in this report were chosen to provide an analysis that encompasses the same range in stringency as in all eight of the alternatives evaluated in the PRIA.

[3] See e.g., Table I-4 of the NHTSA/EPA NPRM (2018a).

Table ES-1. CAFE Regulatory Alternatives

Alternative	Change in stringency
Baseline/ No-Action ("Augural")	MY 2021 standards remain in place; MYs 2022-2025 augural CAFE standards are finalized; MY 2026 standards are set at MY 2025 levels
8	Existing standards through MY 2021, then 2%/year increases for passenger cars and 3%/year increases for light trucks, for MYs 2022-2026
5	Existing standards through MY 2021, then 1%/year increases for passenger cars and 2%/year increases for light trucks, for MYs 2022-2026
1	Existing standards through MY 2020, then 0%/year increases for both passenger cars and light trucks, for MYs 2021-2026

Note: These alternatives assume no changes in treatment of air conditioning efficiency or off-cycle provisions.

Since these standards are footprint-based, the actual miles-per-gallon (MPG) CAFE requirements will vary by automobile manufacturer and will depend on the sales mix of manufacturers' vehicles. To provide an illustration of how the standards differ across scenarios, Table ES-2 provides the average MPG requirements as estimated in the CAFE Model for model years 2021-2026.

Table ES-2. Average CAFE Estimated Requirements by Regulatory Scenario (Passenger Cars and Light Trucks), MY 2021-2026

	Model Year					
Scenario	2021	2022	2023	2024	2025	2026
Augural Stds.	38.9	40.7	42.7	44.7	46.8	46.8
8	38.9	39.9	40.9	42.0	43.1	44.2
5	38.9	39.5	40.1	40.7	41.4	42.0
1	36.9	36.9	36.9	36.9	36.9	36.9

Note: Values represent the estimated combined (i.e., passenger cars and light trucks) light-duty vehicle CAFE MPG requirement. As described in the text, the actual MPG requirements are different for cars and for light trucks and differ also for the various automobile manufacturer depending on each manufacturer's sales mix. The values in Table ES-2 represent average MPG requirement estimates based on sales and MPG values in the CAFE Model for the relevant model years.

Since the augural standards are more stringent than the three alternatives, the results we develop are generally estimates of the *reductions* in social costs and the *reductions* in social benefits due to the three less-stringent CAFE standards. The net benefits of each standard depend upon the relationship of the two reduced values; if the reduction in social costs is greater than the reduction in social benefits, the standard is estimated to lead to a net gain in social welfare (as measured by social benefits and costs); if the reduction in social costs is less than the reduction in social benefits, the standard would lead to a net loss in social welfare.

B. Motor Vehicle Market Impacts

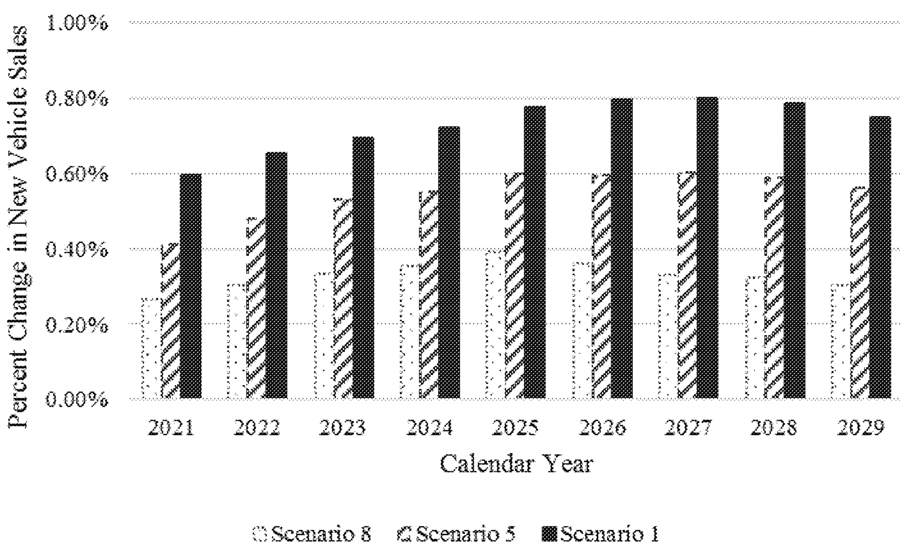
Implementation of the CAFE alternatives would lead to changes for the vehicle fleet, including changes in the age composition of the fleet as well as changes in VMT.

1. Changes in the Vehicle Fleet

a. New Vehicle Sales

The alternative CAFE standards affect new vehicle sales by changing the prices and fuel economy of the new vehicles that are offered for sale and, due to the operation of the market for new vehicles, the number of new vehicles that are sold. Figure ES-2 shows the percentage change in sales by model year for the three alternative CAFE standards as compared to the level of sales under the augural standards. These changes in new vehicle sales reflect the net effects of the decreases in prices and the decreases in in fuel economy (MPG) due to the less-stringent alternative CAFE standards. The alternative CAFE standards are projected to lead to greater new vehicle sales, with the percentage increase varying over the various model years.

Figure ES-2. Differences in New Vehicle Sales Compared to Augural Standards Baseline, MY 2021-2029



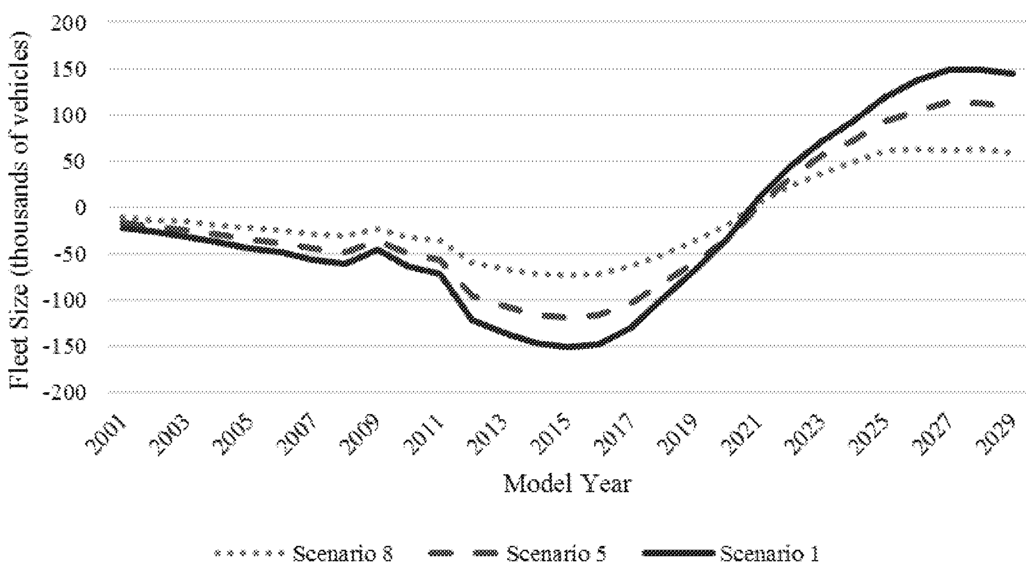
b. Existing Vehicle Scrappage

These changes in new vehicle prices and the values placed on changes in fuel economy are used to estimate a "net" new vehicle price change for each model year, i.e., a percentage increase in new vehicle price that reflects changes in the quality of the new vehicles as measured by changes in MPG. These changes in the "net" prices for new vehicles lead to changes in the existing fleet because new vehicles and existing vehicles are substitutes for one another. Price increases for new vehicles thus would lead to increases in the number of older vehicles (obtained via reduced scrappage of existing vehicles); in the same manner, price decreases for new vehicles will lead to decreases in the number of older vehicles (obtained via increased scrappage of existing vehicles). The net effect of the three alternative CAFE standards thus is to change the age distribution of the vehicle fleet in any given calendar year from that under the augural standards.

c. Age Distribution of the Vehicle Fleet

Figure ES-3 provides an illustration of the fleet effects of the three alternative CAFE standards we evaluate. For a given calendar year, in this case 2030, the figure shows the changes in the number of light-duty vehicles by age due to the three standards. These results show the following expected patterns: (a) sales of new vehicles subject to the CAFE standards increase for the three alternatives (i.e., the less-stringent standards lead to larger sales); and (b) numbers of existing vehicles decrease (i.e., the lower prices for newer vehicles lead to lower prices for existing vehicles and thus more scrappage of existing vehicles). For scale, the estimated fleet size in 2030 is 251 million vehicles under the augural standards. The combined fleet effects under Alternative 1 combine to produce a fleet that includes 0.65 million fewer light-duty vehicles in 2030, reflecting the difference between the increases in new vehicle sales and the decreases in existing vehicles. This difference represents a 0.2 percent change in fleet size relative to the augural standards baseline.

Figure ES-3. Differences in Fleet Effects Compared to Augural Standards Baseline by Model Year, for Calendar Year 2030



2. Changes in Vehicle Miles Traveled

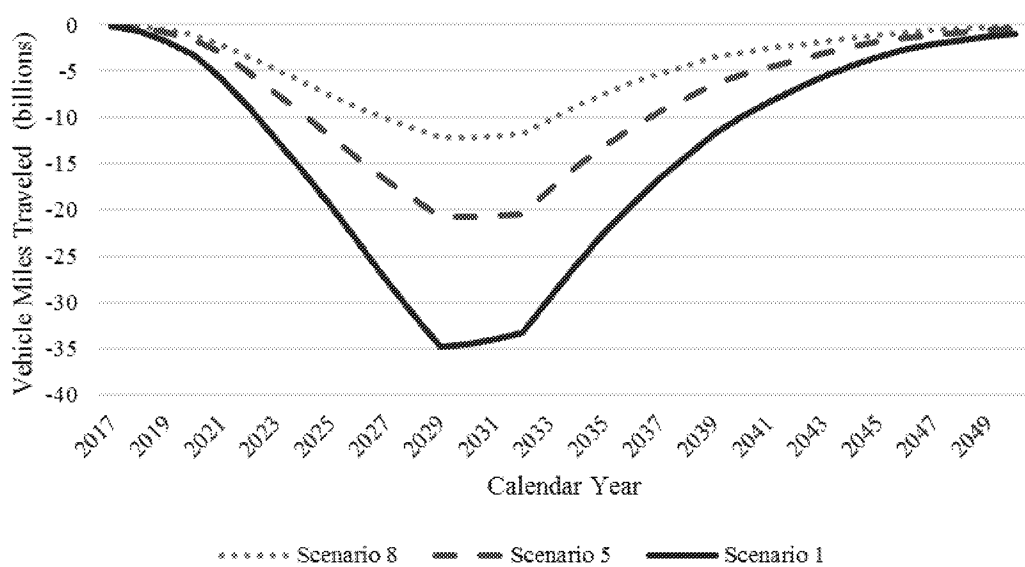
The alternative CAFE standards affect VMT in two ways.

- *Age distribution effects*. Because older vehicles are driven less than newer vehicles, a shift in the age distribution of the fleet would lead to changes in the number of miles traveled.
- *Rebound effects*. Changes to vehicle fuel economy due to the standards would lead to changes in the number of miles traveled for vehicles subject to the standards. Any change

in fuel economy would affect the cost per mile driven and thus (via a demand effect) the number of miles traveled; this is often referred to as the "rebound effect."

Figure ES-4 provides estimates of the effects on VMT of the three alternative CAFE standards relative to the augural standards, showing results for vehicles in the model years covered by our analyses (i.e., up to MY 2029) over the period covered by our analysis (2017 to 2050). Annual VMT is lower for all three alternatives, reflecting the rebound effect (i.e., lower MPG of the new vehicles lead to an increase in the cost/mile and thus a decrease in the number of miles traveled). For scale, estimated total VMT of light-duty vehicles in 2029 is 3.05 trillion miles under the augural standards—thus the 35-billion-mile reduction in VMT under Scenario 1 represents a 1.1 percent reduction.

Figure ES-4. Differences in VMT Compared to Augural Standards Baseline by Calendar Year

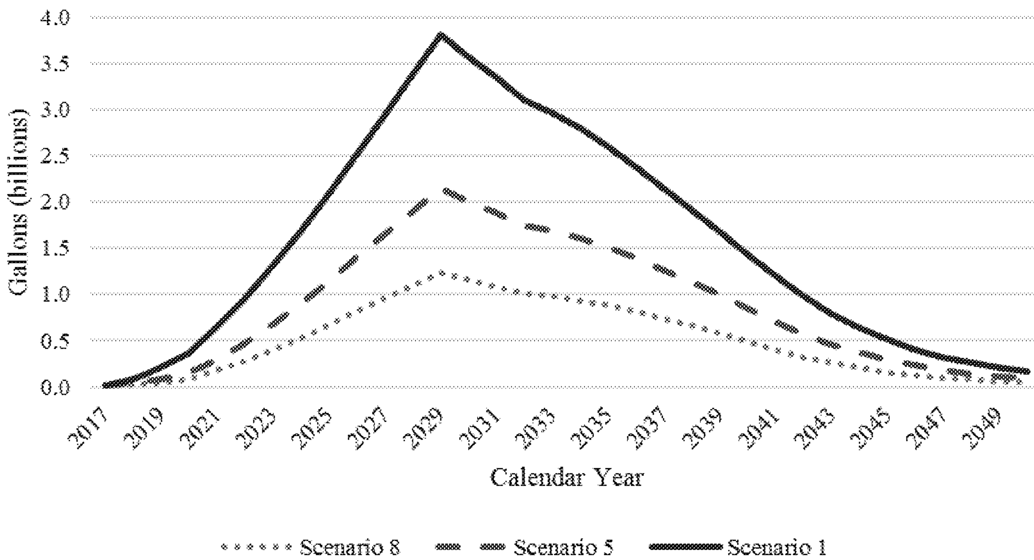


Note that because we include vehicles only up to and including MY 2029, the changes due to the three alternative standards decrease over time as more of the MY 2029 and earlier vehicles are scrapped. By the end of the period (2050), even the "newest" MY 2029 vehicles are 21 years old. This same pattern is evident in all graphs showing effects by calendar year.

3. Changes in Fuel Consumption

The alternative CAFE standards affect motor fuel consumption through effects on the fuel economy of the new vehicles, on the age composition of the vehicle fleet, on the vehicle type mix of the vehicle fleet (i.e., light trucks vs passenger cars) and on the VMT of the fleet. Figure ES-5 provides estimates of the motor fuel consumption (cumulative for gasoline, diesel, and E85) of the three alternative CAFE standards over the analysis period. Estimated fuel consumption increases for all three alternatives relative to the levels under the augural standards, reflecting the lower average MPG of the fleet (an effect that outweighs the effects of fewer VMT). In 2029, estimated light-duty vehicle fuel consumption is 98 billion gallons under the augural standards—thus the 3.8-billion-gallon increase under Scenario 1 represents a 3.9 percent change. Among all uses of motor gasoline and diesel, which are projected to total 166 billion gallons in Annual Energy Outlook 2018 (EIA AEO 2018), this would represent a 1.3 percent change.

Figure ES-5. Differences in Motor Fuel Consumption Compared to Augural Standards Baseline by Calendar Year



Note: Gallon values include gasoline, diesel, and E85 fuel consumption.

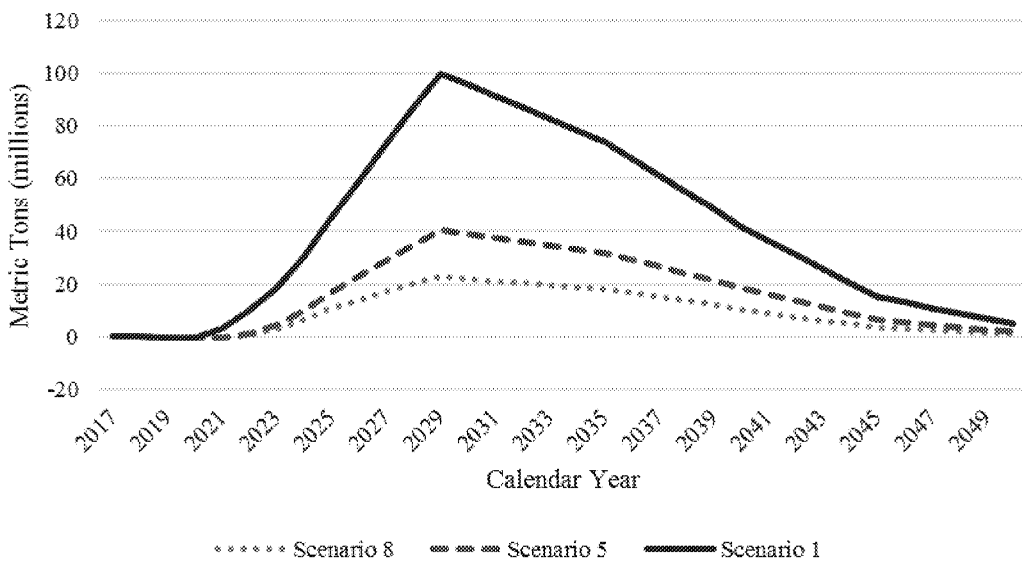
4. Changes in Emissions

The alternative CAFE standards affect tailpipe emissions through changes in the age composition of the fleet and changes in VMT. In addition, changes in fuel use lead to changes in upstream emissions (e.g., refinery emissions). Our modeling includes two general classes of emissions: (a) Greenhouse gas (GHG) emissions, including CO_2 and the other emissions that contribute to overall GHG emissions; and (b) criteria pollutants, which include emissions that affect ambient air quality, either directly or as precursors.

a. Greenhouse Gas Emissions

Figure ES-6 provides estimates of the change in GHG emissions (expressed as CO_2 equivalents) of the three alternative CAFE standards we evaluate over the period covered by our analysis. The GHG emissions increase for all three alternatives relative to the augural standards, reflecting the increase in fuel consumption due to the less fuel-efficient fleets under the less-stringent standards. In 2029, estimated total CO_{2eq} emissions for the light-duty fleet are 1.1 billion metric tons; thus the 99.7 million metric ton increase under Scenario 1 represents an 9.1 percent change in light-duty fleet emissions.

Figure ES-6. Differences in GHG Emissions (CO_{2eq}) relative to Augural Standards Baseline by Calendar Year

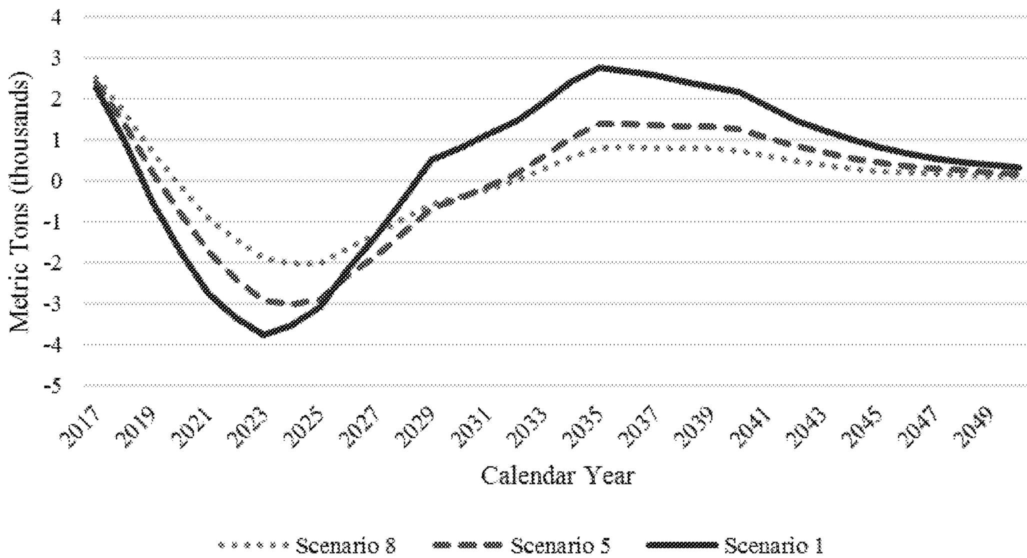


Note: GHG emissions presented as CO_2 equivalents and include CO_2, N_2O, and CH_4 emissions.

b. Criteria Pollutant Emissions

Figure 8 provides estimates of the changes in NO_X emissions—one of the major criteria pollutants affected by the CAFE alternatives—due to the three alternative CAFE standards. (Results for the other pollutants are presented in the report.) The changes in NO_x emissions are due both to changes in tailpipe emissions and changes in upstream emissions. Tailpipe emissions of NOx are lower for all three alternatives relative to the augural standards baseline, reflecting the accelerated scrappage of older vehicles under the less-stringent standards. In contrast, upstream emissions of NOx increase relative to the augural standards because of increases in demand for motor fuel, based on the agencies' current analysis, which we adopt for purposes of this study. The net effect results in changes in NO_X emissions relative to the augural standards baseline that are generally lower in the early years (as tailpipe emissions reductions exceed upstream emissions increases) and generally higher in the later years (as upstream emissions increases exceed tailpipe emissions reductions) under the alternative CAFE standards. As with all effects, by the end of the period the net changes are small because MY 2029 and earlier motor vehicles become a small part of the vehicle fleet.

Figure ES-7. Differences in NO_X Emissions relative to Augural Standards Baseline by Calendar Year



C. Social Costs and Social Benefits

1. Categories of Social Costs and Social Benefits

The modeling framework outlined above allows us to develop estimates of the social costs and social benefits of the three alternative CAFE standards. Our identification of social cost and social benefit categories draws on the framework developed in the PRIA. We include the following four major social cost categories.

1. *New vehicle technology costs.* These costs include the costs of the technologies to achieve compliance with the various CAFE standards.
2. *Congestion costs.* Changes in VMT lead to changes in the congestion costs that motorists incur on the road.
3. *Noise costs.* Changes in VMT lead to changes in the noise levels that motorists experience.
4. *Crash costs.* Changes in the vehicle fleet and VMT lead to changes in fatal and non-fatal crash costs.

We include the following five major social benefits categories.

1. *Fuel economy benefits.* Improvements in new vehicle fuel economy allow drivers to consume less fuel per mile driven, leading to lower fuel expenditures, more VMT (due to the lower cost per mile, i.e., rebound effect), and less time spent refueling.

2. *Fuel tax revenue benefits.* Changes in fuel expenditures lead to changes in tax revenue collected from motor fuel sales. Note that fuel tax payments are part of consumer fuel expenditures, which are a component of consumers' valuation of fuel economy changes.

3. *Petroleum market externality benefits.* Changes in gasoline demand lead to changes in the market price of petroleum and thus have an external effect beyond the effects experienced by new vehicle purchasers.

4. *Greenhouse gas (GHG) emissions benefits.* Changes in VMT, changes in the vehicle fleet, and changes in fuel use affect the levels of CO_2 and other GHG emissions.

5. *Criteria pollutant emissions benefits.* Changes in VMT, changes in the vehicle fleet, and changes in fuel use also affect the levels of criteria pollutant emissions. We calculate dollar estimates for four criteria pollutants, including NOx, VOC, PM, and SO_2.

2. Net Benefit Results

Table ES-3 shows the social costs, social benefits and net benefits of the three CAFE alternatives relative to the augural standards using a 3 percent discount rate; results using a 7 percent discount rate are provided in Table ES-4. The values include effects for model year vehicles up to MY 2029 based on impacts in calendar years from 2017 to 2050. Because the baseline ("no action" alternative) is the most stringent set of standards (augural standards), as noted above, the values for social costs for the three less-stringent CAFE standards evaluated are all negative, i.e., the values show the cost savings from less-stringent standards. Similarly, because the baseline is the most stringent standard, the values for social benefits for the three less-stringent CAFE standards also are generally negative, i.e., most categories show reductions in benefits from setting less-stringent standards. The exceptions are government fuel tax revenue (which is greater due to increased fuel use under Scenarios 8, 5, and 1), and two of the four criteria pollutants (in which reductions in tailpipe emissions essentially cancel out increases in upstream emissions, leading virtually no net change in benefits).

Table ES-3. Net Benefits Relative to Augural Standards Baseline, 3% Discount Rate (billions of 2016$)

	Scenario 8	Scenario 5	Scenario 1
Social Costs			
Technology Costs	-68.8	-113.9	-170.7
Congestion Costs	-6.3	-10.6	-17.9
Noise Costs	-0.1	-0.2	-0.3
Fatal Crash Costs	-1.1	-1.3	-1.0
Non-Fatal Crash Costs	-1.5	-1.7	-1.3
Total Social Costs	**-77.7**	**-127.7**	**-191.2**
Social Benefits			
Valuation of Fuel Economy Benefits	-28.0	-49.0	-87.2
Fuel Tax Revenue Benefits	4.3	7.4	13.2
Petroleum Market Externality Benefits	-1.3	-2.2	-3.9
GHG Damage Reduction Benefits	-1.6	-2.9	-7.1
NO_x Damage Reduction Benefits	0.0	0.1	0.0
VOC Damage Reduction Benefits	0.0	-0.1	-0.1
$PM_{2.5}$ Damage Reduction Benefits	-0.4	-0.8	-1.7
SO_2 Damage Reduction Benefits	-2.0	-3.4	-6.1
Total Social Benefits	**-29.0**	**-50.9**	**-93.0**
Net Total Benefits	**48.7**	**76.8**	**98.2**

Note: Present values calculated as of January 1, 2017 using a 3 percent discount rate for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. GHG damage reduction benefits values include benefits associated CO_2, as well as other GHG pollutants, which have been converted to CO_{2eq}. Values may not sum to totals due to rounding.

Source: NERA/Trinity calculations as explained in text.

Table ES-4. Net Benefits Relative to Augural Standards Baseline, 7% Discount Rate (Billions of 2016$)

	Scenario 8	Scenario 5	Scenario 1
Social Costs			
Technology Costs	-51.8	-85.4	-128.5
Congestion Costs	-3.9	-6.5	-10.9
Noise Costs	-0.1	-0.1	-0.2
Fatal Crash Costs	-0.9	-1.1	-1.0
Non-Fatal Crash Costs	-1.2	-1.4	-1.3
Total Social Costs	**-57.8**	**-94.5**	**-141.8**
Social Benefits			
Valuation of Fuel Economy Benefits	-19.1	-33.3	-59.5
Fuel Tax Revenue Benefits	2.6	4.4	8.0
Petroleum Market Externality Benefits	-0.8	-1.3	-2.3
GHG Damage Reduction Benefits	-0.2	-0.3	-0.7
NO_x Damage Reduction Benefits	0.0	0.1	0.0
VOC Damage Reduction Benefits	0.0	0.0	-0.1
$PM_{2.5}$ Damage Reduction Benefits	-0.2	-0.5	-1.0
SO_2 Damage Reduction Benefits	-1.2	-2.0	-3.6
Total Social Benefits	**-18.9**	**-32.9**	**-59.3**
Net Total Benefits	**38.9**	**61.6**	**82.6**

Note: Present values calculated as of January 1, 2017 using a 7 percent discount rate for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. GHG damage reduction benefits values include benefits associated CO_2, as well as other GHG pollutants, which have been converted to CO_{2eq}. Values may not sum to totals due to rounding.

Source: NERA/Trinity calculations as explained in text.

These results using both a 3 percent and 7 percent discount rate indicate that all three alternatives would lead to net benefits, i.e., the reductions in social costs would be greater than the reductions in social benefits if any of the three CAFE alternatives replaced the Augural standards.

I. Introduction

This report evaluates alternative corporate average fuel economy (CAFE) standards for passenger cars and light trucks (collectively, "vehicles") for model year (MY) 2021 to MY 2026.[4] The evaluations are based upon a suite of models that include those developed by government agencies as well as those developed by NERA Economic Consulting (NERA) and Trinity Consultants (Trinity).

Our evaluations include estimates of the market effects and other regulatory impacts (e.g., changes in new vehicle sales and emissions) of alternative CAFE standards as well as estimates of the societal costs and societal benefits of these standards. These estimates result in estimates of the net benefits (i.e., social benefits minus social costs) of alternatives.

A. Regulatory Background

In August 2018, NHTSA and EPA jointly released a notice of proposed rulemaking (NPRM)—the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks (SAFE Vehicles Rule)—along with supporting materials that included a preliminary regulatory impact analysis (PRIA). In the PRIA, NHTSA and EPA evaluated eight alternatives, all relative to the current set of standards (which is the "no action" alternative). This no action alternative assumes that the MY 2021 standards remain in place, that the MY 2022-2025 Augural CAFE standards are finalized and that MY 2026 standards are set at MY 2025 levels.[5] For ease of exposition, we refer to this baseline scenario as the "augural standards baseline." Note that our analyses evaluate alternative CAFE standards relative to this augural standards baseline. Table 1 summarizes the eight alternative standards noted in the NRPM. The Baseline/No-Action alternative is included at the end of the table, reflecting the fact that it is the most stringent of the alternatives evaluated.

[4] NHTSA and EPA also evaluated standards for carbon dioxide (CO_2) emissions for the same model years. We estimate effects of the alternative CAFE standards and do not develop separate estimates for alternative CO_2 standards. Since the two sets of standards are harmonized, however, our comparative results for the alternative CAFE standards should apply to the equivalent CO_2 standards (although the specific estimates would differ).

[5] See e.g., Table I-4 of the NHTSA/EPA NPRM (2018a).

Table 1. CAFE Alternatives Evaluated in the NHTSA/EPA NPRM

Alternative	Change in Stringency	A/C efficiency and off-cycle provisions.
1	Existing standards through MY 2020, then 0%/year increases for both passenger cars and light trucks, for MYs 2021-2026	No change
2	Existing standards through MY 2020, then 0.5%/year increases for both passenger cars and light trucks, for MYs 2021-2026	No change
3	Existing standards through MY 2020, then 0.5%/year increases for both passenger cars and light trucks, for MYs 2021-2026	Phase out these adjustments over MYs 2022-2026
4	Existing standards through MY 2020, then 1%/year increases for passenger cars and 2%/year increases for light trucks, for MYs 2021-2026	No change
5	Existing standards through MY 2021, then 1%/year increases for passenger cars and 2%/year increases for light trucks, for MYs 2022-2026	No change
6	Existing standards through MY 2020, then 2%/year increases for passenger cars and 3%/year increases for light trucks, for MYs 2021-2026	No change
7	Existing standards through MY 2020, then 2%/year increases for passenger cars and 3%/year increases for light trucks, for MYs 2021-2026	Phase out these adjustments over MYs 2022-2026
8	Existing standards through MY 2021, then 2%/year increases for passenger cars and 3%/year increases for light trucks, for MYs 2022-2026	No change
Baseline/ No-Action	MY 2021 standards remain in place; MYs 2022-2025 augural CAFE standards are finalized; MY 2026 standards are set at MY 2025 level	No change

Source: NHTSA/EPA (2018a).

B. Objective of this Study

The principal objective of this study is to estimate the potential impacts of alternative CAFE standards using a combination of models including those used by NHTSA in the PRIA as well as those developed by NERA and Trinity for this study. The NERA models include a model of the new vehicle market that provides estimates of the values that new vehicle purchasers place on changes in fuel economy as well as a model of the relationship between changes in new vehicle prices and changes in the scrappage of different vintages of existing vehicles. We rely upon information developed by NHTSA for estimates of the identification, cost and effectiveness of alternative technologies to improve fuel economy for individual manufacturers and motor vehicle models—information that is contained in the version of the CAFE Model that was released by NHTSA when the NPRM was released. (This model was previously identified as the Volpe Model.)

We develop estimates for three of the eight alternatives that were included in the PRIA, as shown in Table 2. The three alternatives correspond to Alternative 1, Alternative 5, and Alternative 8 and thus span the range of stringency included in the PRIA. As in the PRIA, we evaluate each of the three alternatives relative to the "no action" augural standards, which are more stringent than any of the three alternatives. Note that throughout this report we order the alternatives in terms of decreasing stringency, i.e., Alternative 8, 5 and 1, all of which are less stringent than the baseline augural standards.

Table 2. CAFE Alternatives Evaluated in This Study

Alternative	Change in stringency
Baseline/ No-Action ("Augural")	MY 2021 standards remain in place; MYs 2022-2025 augural CAFE standards are finalized; MY 2026 standards are set at MY 2025 levels
8	Existing standards through MY 2021, then 2%/year increases for passenger cars and 3%/year increases for light trucks, for MYs 2022-2026
5	Existing standards through MY 2021, then 1%/year increases for passenger cars and 2%/year increases for light trucks, for MYs 2022-2026
1	Existing standards through MY 2020, then 0%/year increases for both passenger cars and light trucks, for MYs 2021-2026

Note: There are no changes in A/C Efficiency or off-cycle provisions between these alternatives.

C. Outline of the Report

The remainder of this report is organized as follows. Chapter II provides information on our methodology for evaluating the effects of the alternative CAFE standards, including information on the various models used in the analyses. Chapter III provides estimates of the market and regulatory impacts of the three alternative CAFE standards, including impacts on new vehicle sales, fleet population effects, VMT, gasoline consumption and air emissions. Chapter IV provides estimates of changes in social costs, including the costs to modify new motor vehicles as well as various costs related to changes in VMT (congestion, noise and crash costs). Chapter V provides estimates of changes in social benefits, including the value of fuel economy changes, VMT changes, refueling time changes, changes in government fuel tax revenues as well as market externality effects of changes in fuel use and changes in emissions benefits for greenhouse gas (GHG) emissions and criteria pollutant emissions. Chapter VI provides estimates of the net benefits (i.e., benefits minus costs) of the three alternatives. Various appendices provide information on the models and details regarding the analyses that underlie the estimates.

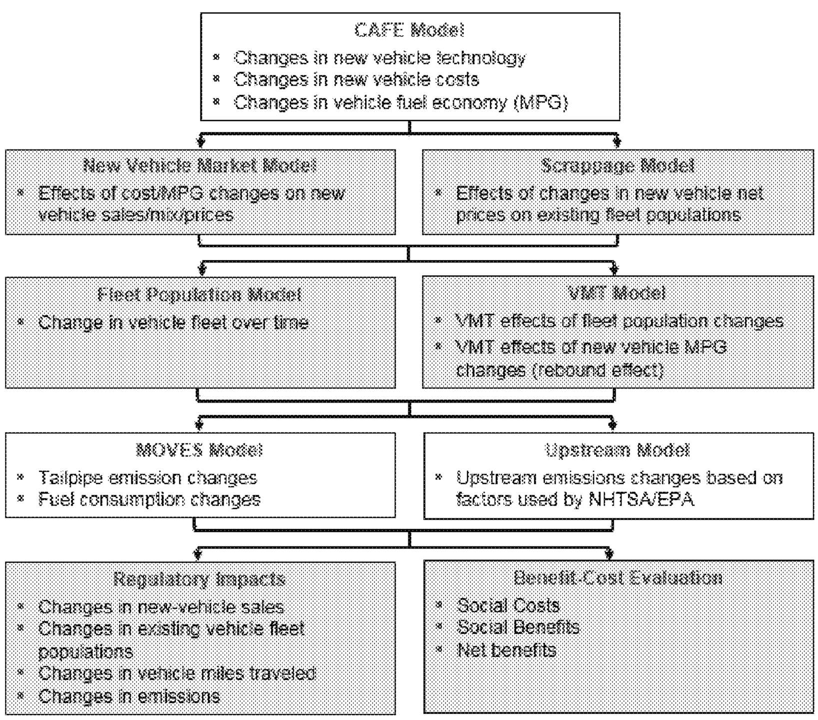
II. Modeling Methodology

This chapter provides information on the methodologies used to estimate the effects of the alternative CAFE standards on the vehicle fleet, on VMT, on fuel consumption, and on emissions. As noted, appendices to this report provide details on the individual models and the data that was used in their estimation and implementation.

A. Overview of Modeling Structure

The modeling framework allows us to estimate the impacts of alternative CAFE standards on the motor vehicle fleet—including changes in new vehicle sales and changes in the scrappage of existing vehicles—as well as on VMT over the analysis period, which is from 2017 to 2050. Results are developed for vehicles and VMT for model years (MY) through MY 2029. Figure 1 provides an overview of the framework, showing the models used and their interactions, with models in white those developed by government agencies and models in blue developed by NERA and Trinity. Details regarding these models are provided in appendices.

Figure 1. Overview of Model Structure



B. CAFE Model

The 2018 CAFE Model[6] developed by the U.S. Department of Transportation (DOT)—subsequently referred to in this report as the CAFE Model—was used as the first element of the modeling. Trinity used the CAFE Model to estimate changes in new vehicle technology penetrations, costs and fuel economy/CO_2 emissions by model year for the U.S. light-duty vehicle fleet under the alternative CAFE standards. Table 2 above summarizes the three alternative sets of CAFE standards that were evaluated, all relative to the augural standards that constitute the baseline.

The CAFE Model input files and run configuration options were generally set to those used by NHTSA to support the "Unconstrained" analysis[7] referred to in the Draft Environmental Impact Analysis (DEIS). Trinity did not modify any of the basic information on the costs and effectiveness of technology options to improve vehicle fuel economy that are included in the CAFE Model. Appendix A contains information on the CAFE Model and the implementation in this analysis.

C. New Vehicle Market Model

NERA developed the New Vehicle Market Model, a model of the U.S. market for new vehicles that is used to analyze the effects of alternative CAFE standards on new vehicle sales and prices. The New Vehicle Market Model has the structure of a nested logit model, a formulation that has been used extensively by economists to characterize motor vehicle markets.[8] The model is calibrated and estimated using data on transaction prices and other vehicle characteristics for almost 300 individual models for vehicles in model year (MY) 2013 to MY 2017. The New Vehicle Market Model allows us to estimate the value that new vehicle purchasers place on fuel economy improvements (via changes in operating costs) based upon observed market behavior. The model also allows us to calculate net price increases for new vehicles—i.e., price increases net of the value that new vehicle purchasers place on fuel economy changes—due to the alternative standards.

The New Vehicle Market Model is an improvement over estimates of the value of fuel economy and new vehicle choice based upon assumed payback periods and other *ad hoc* approaches.[9]

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[6] The version of the CAFE Model used for this analysis was the "2018 NRPM" version released by the National Traffic Safety Administration in August, 2018 in support of the proposed NPRM: https://www.nhtsa.gov/corporate-average-fuel-economy/compliance-and-effects-modeling-system.

[7] As described in Section 2.3.2 of the DEIS, NHTSA's CAFE Model results presented in the NPRM and PRIA differ slightly from those presented in the DEIS. The Energy Policy and Conservation ACT (EPCA) and Energy Independence and Security Act (EISA) require that the Secretary determine the maximum feasible levels of CAFE standards in a manner that sets aside the potential use of CAFE credits or application of alternative fuels toward compliance with new standards. NEPA, however, does not impose such constraints on analysis; instead, its purpose is to ensure that "public officials make decisions with an understanding of environmental consequences." The DEIS therefore presents results of an "unconstrained" analysis that considers manufacturers' potential use of CAFE credits and application of alternative fuels in order to disclose and allow consideration of the real-world environmental consequences of the Proposed Action and alternatives.

[8] See, e.g., Bunch et al. (2011); Harrison et al. (2008); Greene et al. (2005); Train (1986); and Ben Akiva and Lerman (1985).

[9] See e.g., Greene (2012), pp. 18-19 for a discussion of various methodologies used to estimate consumer valuations of fuel economy.

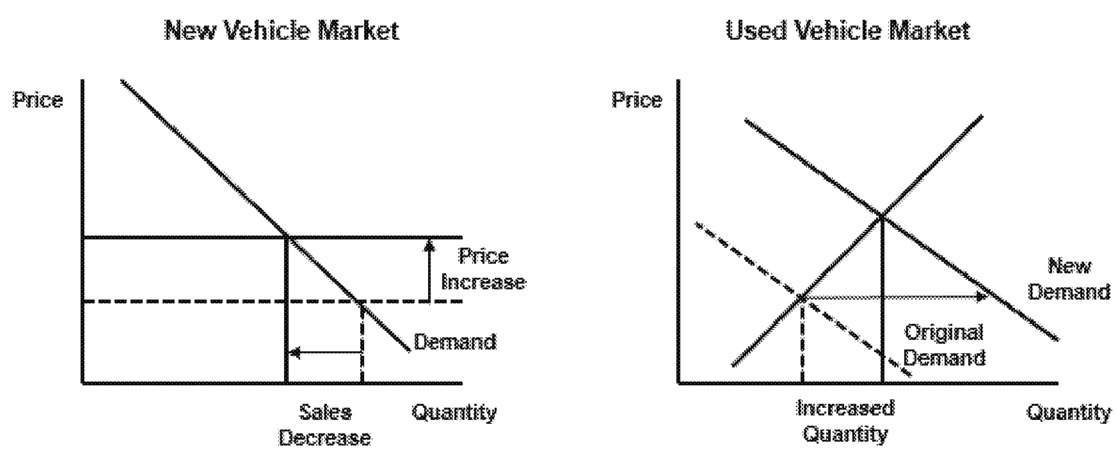
Using results from the New Vehicle Market Model and estimates from the CAFE Model of changes in costs and fuel economies for various models due to the alternative standards, we develop estimates of the changes in new vehicle sales due to the alternative standards. Appendix B provides a detailed description of the data and statistical methodologies used to develop the New Vehicle Market Model as well as the model results.

D. Scrappage Model

Previous research has established that new vehicle prices affect used vehicle scrappage rates.[10] Using a conceptual framework developed by previous researchers, we have developed an updated statistical model relating used-vehicle scrappage rates to new vehicle prices. The Scrappage Model includes statistically-estimated relationships between scrappage rates for vehicles of different model year vintages at each age during their lifetimes to new vehicle prices and other relevant factors.

Figure 2 provides a simple illustration of the effects of changes in the new vehicle market on the used vehicle market. The left-hand figure illustrates the case for the new vehicle market if CAFE standards lead to a net increase in the cost of new vehicles (i.e., costs greater than value of fuel economy gains), leading to an increase in price and a decrease in new vehicle sales. Because new vehicles are more expensive, the demand for used vehicles (a substitute good) increases, an effect illustrated in the right-hand figure. The increased demand for used vehicles leads to increases in their prices as well as increases in the quantity of used vehicles in the fleet. The change in quantity occurs from changes in scrappage rates; if used vehicles command higher prices, this provides a market signal to keep existing vehicles longer and thus scrappage rates decline. Note that this simple diagram abstracts from many specifics of the potential impacts on the existing fleet (e.g., scrappage effects differ by existing vehicle age). Appendix C provides a description of the Scrappage Model, including the data we use and the statistical estimates of the effects of changes in the new vehicle price on scrappage rates, accounting for other determinants of scrappage rates.

Figure 2. Effects of Changes in New Vehicles Prices on Prices/Quantities of Used Vehicles



[10] See, e.g., Gruenspecht (1983), as referenced in Appendix C.

These changes in vehicle scrappage due to CAFE standards are important because many of the effects of CAFE standards depend upon effects on the vehicle fleet. For example, criteria pollutants are affected by existing vehicle scrappage rates in two ways: (a) vehicles sold in the past were subject to less stringent standards; and (b) as vehicles age, their emission rates increase, whatever the emission rates were when the vehicles were new. For both reasons, additional older vehicles on the road will mean increased emissions. In addition, to the extent that older vehicles are less fuel efficient than new ones, having more older vehicles on the road would tend to reduce average fuel economy and thus also raise GHG emissions. Of course, the opposite effects would occur if there are fewer older vehicles on the road; everything else equal, fewer older vehicles would mean lower emissions of criteria emissions and GHG emissions.

E. Fleet Population Model

The Fleet Population Model combines the results of the New Vehicle Market Model and the Scrappage Model to project changes in vehicle fleet populations over time. The empirical results from the Scrappage Model are used in combination with the new vehicle sales effects from the New Vehicle Market Model to estimate the net effects of the alternative standards on the U.S. vehicle fleet over time. The Fleet Population Model keeps track of vehicles in model years up to MY 2029 over the analysis period from 2017 to 2050.

The baseline forecast of the relevant U.S. vehicle fleet population is based upon the vehicle populations in EPA's MOVES vehicle emission inventory model (see below). Fleet population effects due to the CAFE alternatives are measured relative to this baseline vehicle fleet population for MY 2029 and earlier vehicles. Appendix D provides more detailed information on the Fleet Population Model.

F. Vehicle Miles Traveled (VMT) Model

Many of the effects of the alternative CAFE standards depend upon impacts on VMT, including changes in safety, congestion and vehicle emissions. The results of the Fleet Population Model provide one important component of the VMT model to the extent that total fleet VMT could be influenced by the size and/or age-distribution of the fleet. Because older vehicles tend to be driven less than newer vehicles, changes in the age composition of the vehicle fleet would lead to changes in VMT. Similarly, if CAFE standards affect the size of the fleet through sales and scrappage effects that do not exactly offset, then total VMT could be affected. In our modeling, both sources of changes to fleet VMT are relatively small compared to the key component of the VMT model: changes in fuel economy for vehicles subject to the CAFE alternatives lead to changes in the cost of driving, which leads to an additional effect of the alternatives on VMT.

Improvements in fuel economy, as reflected in higher MPG, decrease the cost of driving and thus via a demand effect will lead to greater driving (VMT). This effect applies to all policies that affect energy efficiency and thus lead to a decrease in the price of energy and an increase in energy use; this effect is referred to as a "rebound effect" because the effect offsets in part the direct effect that leads to less energy use.

The rebound effect is defined as the elasticity of VMT with respect to fuel efficiency improvements, i.e., the percentage change in VMT associated with a one-percent change in fuel efficiency. (Reported elasticity estimates typically are multiplied by 100 so the rebound effect is expressed as a percentage, e.g., an elasticity of 0.2 is translated into a rebound effect of 20 percent, meaning that the percent increase in VMT is 20 percent of the percentage improvement in fuel efficiency.) Empirical estimates of the rebound effect are often based on estimated changes in VMT with respect to changes in fuel cost per mile or fuel prices.

The VMT Model starts with baseline VMT estimates by calendar year (from 2017 to 2050) based upon information on VMT by model year provided in the MOVES model. As noted above, our analyses include information on vehicles in model years up to MY 2029 and thus we do not include information from MOVES for vehicles in model years after 2029. We model the effects of the CAFE alternatives on VMT by including the two effects noted above: (a) changes due to modifications in the vehicle fleet as estimated for new vehicles in each year by the New Vehicle Market Model and for the existing fleet by the Scrappage Model; and (b) changes due to the rebound effect, which changes VMT for vehicles in the model years with differences in fuel economy due to the CAFE alternatives.

Appendix E provides information on the VMT Model including our determination of an appropriate rebound effect based on an assessment of the substantial empirical literature. We conclude that 20 percent is the most likely estimate of the rebound effect based upon the available studies.

G. Emissions Modeling

1. MOVES Model

MOVES (for Motor Vehicle Emissions Simulator) is the vehicle emissions model developed by the U.S. EPA to estimate criteria pollutant and CO_2-equivalent emissions from U.S. on-road motor vehicles over nationwide, regional and localized scales under a wide range of fleet characteristics, ambient conditions, and operating conditions. MOVES is based on exhaustive vehicle emission testing measurements collected under both laboratory and in-use conditions and is designed to estimate on-road vehicle fleet emissions and changes over time from on-going changes to federal new vehicle emission standards as well as local control programs.

The latest version of MOVES, MOVES2014b (released in August 2018) was used by Trinity to estimate the change in CO_2-equivalent and criteria pollutant emissions for the U.S. vehicle fleet due to the alternative CAFE standards. These vehicle emissions estimates used estimates of future light-duty vehicle fleets developed by NERA, which as summarized above accounted for the 20 percent rebound effect as well as new vehicle purchase and scrappage effects.

Unlike the CAFE Model, MOVES does not evaluate CO_2-equivalent and criteria emissions impacts of alternative CAFE standards. The values in MOVES reflect the augural standards. Trinity adjusted MOVES CO_2 and criteria emissions to reflect the fuel economy/CO_2 emission rate differences between the augural standards and the three CAFE alternatives evaluated in this study. Appendix F provides further details on how MOVES was used to estimate U.S. light-duty vehicle fleet emission changes and fuel consumption changes.

2. Upstream Model

Upstream emissions refer to the emissions associated with fuel production including refining, distribution, and delivery. The Upstream Model consists of estimates of upstream emissions factors used by NHTSA/EPA in the PRIA that are included in the CAFE Model parameters file. The PRIA notes that the upstream emission factors relied on by the agencies for each fuel type are based on the energy content and emission rates per unit of fuel energy refined and distributed, as developed using the GREET Model developed by Argonne National Laboratories.

We convert these values (which are in grams per million BTUs) to grams per gallon based on the energy density assumptions for each relevant fuel type included in the CAFE Model parameters file. We then apply these factors to the changes in fuel consumption that we estimate based on our fleet population and VMT modeling. Appendix G provides further details on how we applied the NHTSA/EPA PRIA upstream emissions factors to develop estimates of upstream emissions for the alterative standards.

III. Motor Vehicle Market Impacts of Alternative CAFE Standards

This chapter summarizes the results of our analyses of the effects of alternative CAFE standards on motor vehicle markets and related impacts. The results are grouped into five categories:

1. New vehicle sales effects;
2. Existing vehicle scrappage and fleet population effects;
3. Vehicle miles traveled effects;
4. Gasoline and petroleum effects; and
5. Emissions effects.

The results reflect changes due to the three alternative CAFE standards relative to the baseline or no-action (augural) standards. As a result, positive values indicate that the quantity (e.g., new vehicle sales) is greater under the three alternatives than under the augural standards, whereas negative quantities indicate that the quantity (e.g., VMT) is smaller under the three alternatives than under the augural standards.

A. Impacts on New Vehicle Sales

Table 3 shows estimates of total new vehicle sales for MY 2021 to MY 2029 for the three alternatives as well as the augural standards (baseline). Table 4 shows estimates of the *differences* between each of the alternative standards and the augural standards baseline. Table 5 provides the differences in percentage terms. These results show that all three alternative standards would lead to increases in vehicle sales, which reflects estimates that all three standards would lead to decreases in the net price of new vehicles (i.e., the decrease in price is greater than the decrease in the value that new vehicle purchases place on the reduced fuel economy). The changes in costs and fuel economy for new vehicles are based upon the CAFE Model results CAFE Model; the valuations of changes in fuel economy are based upon results from the New Vehicle Market Model.

Table 3. New Vehicle Sales (thousands), MY 2021-2029

Model Year	Augural standards	Scenario 8	Scenario 5	Scenario 1
2021	17,953	18,001	18,027	18,060
2022	17,990	18,044	18,077	18,107
2023	18,039	18,099	18,135	18,164
2024	18,122	18,186	18,222	18,252
2025	18,479	18,551	18,590	18,622
2026	18,804	18,872	18,917	18,954
2027	19,058	19,121	19,174	19,210
2028	19,243	19,306	19,357	19,395
2029	19,345	19,404	19,455	19,490

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

Table 4. Differences in New Vehicle Sales (thousands) Compared to Augural Standards Baseline, MY 2021-2029

Model Year	Augural standards	Scenario 8	Scenario 5	Scenario 1
2021	--	48	74	107
2022	--	55	87	117
2023	--	60	96	125
2024	--	64	100	131
2025	--	73	111	143
2026	--	68	113	150
2027	--	63	116	153
2028	--	63	114	151
2029	--	59	109	145

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

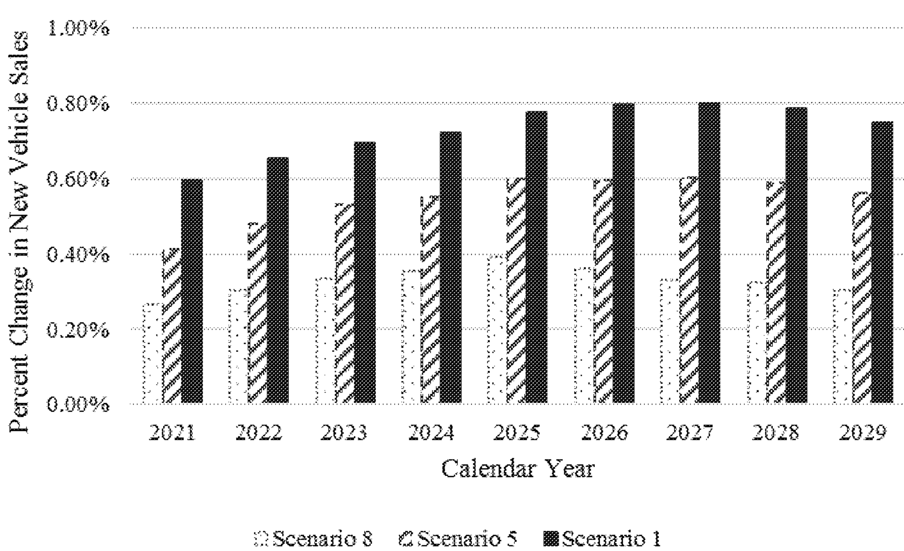
Table 5. Differences in New Vehicle Sales (% Change) Compared to Augural Standards Baseline, MY 2021-2029

	Augural standards	Scenario 8	Scenario 5	Scenario 1
2021	--	0.27%	0.41%	0.60%
2022	--	0.30%	0.48%	0.65%
2023	--	0.33%	0.53%	0.69%
2024	--	0.35%	0.55%	0.72%
2025	--	0.39%	0.60%	0.77%
2026	--	0.36%	0.60%	0.80%
2027	--	0.33%	0.61%	0.80%
2028	--	0.33%	0.59%	0.79%
2029	--	0.31%	0.56%	0.75%

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

The estimated changes in new vehicle sales vary among the three alternative CAFE standards as well as across model years. For MY 2025, for example, the estimated increase in new vehicle sales ranges from 73,000 vehicles for Alternative 8 to 143,000 vehicles for Alternative 1. Figure 3 shows these estimates as percentage changes relative to new vehicle sales under the augural standards. Over all nine model years, the average percentage increase in motor vehicle sales is 0.33% for Alternative 8, 0.55% for Alternative 5, and 0.73% for Alternative 1.

Figure 3. Percentage Differences in New Vehicle Sales Compared to Augural Standards Baseline, MY 2021-2029



Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

B. Impacts on Existing Vehicle Scrappage and Fleet Populations

Decreases in net new vehicle prices due to the alternative standards would lead to changes in the scrappage rates of older vehicles. Specifically, the lower net new car prices and increased numbers of new vehicles due to the less stringent CAFE standards would lead to reductions in the numbers of used vehicles on the road; these reductions would be accomplished by increases in the scrappage rates for existing vehicles. In any calendar year, the combination of the increase in new vehicle sales and the decrease in existing vehicles (through increased scrappage) would combine to change the overall vehicle fleet. The combined effect of more newer vehicles and fewer existing vehicles would lead to a gradual reduction in the average age of the vehicle fleet.

To provide an example of the estimated effects of the alternative CAFE standards on the motor vehicle fleet, Table 6 shows the numbers of vehicles by model year in 2030 under the three alternatives as well as the augural standards (baseline). The table shows the number of vehicles by model year (starting in MY 2001) that are estimated to make up the motor vehicle fleet in 2030.

Table 6. Number of Vehicles (thousands) by Model Year in Calendar Year 2030

Model Year	Augural Standards	Scenario 8	Scenario 5	Scenario 1
2001	368	357	351	347
2002	470	457	449	443
2003	561	545	537	530
2004	692	673	663	654
2005	834	812	800	790
2006	965	941	927	916
2007	1,190	1,162	1,146	1,133
2008	1,348	1,319	1,301	1,288
2009	1,106	1,083	1,070	1,060
2010	1,663	1,632	1,613	1,600
2011	2,066	2,031	2,009	1,994
2012	3,940	3,881	3,845	3,819
2013	5,039	4,973	4,933	4,904
2014	6,459	6,388	6,343	6,312
2015	8,034	7,961	7,915	7,883
2016	9,823	9,752	9,707	9,676
2017	11,375	11,312	11,272	11,245
2018	12,405	12,355	12,324	12,307
2019	13,188	13,152	13,128	13,121
2020	13,980	13,962	13,947	13,946
2021	14,766	14,772	14,768	14,777
2022	15,499	15,521	15,529	15,542
2023	16,153	16,190	16,209	16,225
2024	16,741	16,789	16,814	16,835
2025	17,497	17,559	17,590	17,616
2026	18,137	18,200	18,241	18,275
2027	18,633	18,695	18,746	18,782
2028	18,959	19,022	19,072	19,108
2029	19,203	19,262	19,312	19,347

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

Table 7 and Table 8 show the *differences* in the number of motor vehicles by model year relative to the augural standards baseline levels, both in absolute and percentage terms. In 2030, the number of vehicles on the road is greater than under the augural standards for the nine newest model years, while the number is smaller for the earlier model years. Note that the scrappage effect operates on model years that have larger new vehicle sales under the less-stringent standards. For MY 2021, for example, Table 4 shows an estimated 107,000 additional new vehicle sales under Alternative 1 relative to the augural standards; by 2030, however, accelerated scrappage results in only 11,000 more MY 2021 vehicles still on the road if Alternative 1 replaced the augural standards.

Table 7. Differences in Number of Vehicles (thousands) Compared to Augural Standards Baseline by Model Year in Calendar Year 2030

Model Year	Augural Standards	Scenario 8	Scenario 5	Scenario 1
2001	--	-10	-16	-21
2002	--	-13	-21	-26
2003	--	-15	-24	-31
2004	--	-18	-29	-37
2005	--	-22	-34	-43
2006	--	-24	-38	-48
2007	--	-28	-44	-56
2008	--	-30	-47	-60
2009	--	-23	-36	-46
2010	--	-31	-50	-63
2011	--	-35	-56	-72
2012	--	-59	-95	-121
2013	--	-65	-106	-135
2014	--	-71	-115	-147
2015	--	-73	-119	-151
2016	--	-72	-116	-148
2017	--	-63	-103	-129
2018	--	-50	-81	-98
2019	--	-36	-59	-67
2020	--	-19	-34	-34
2021	--	5	1	11
2022	--	22	31	43
2023	--	37	55	71
2024	--	48	73	94
2025	--	62	93	119
2026	--	63	104	138
2027	--	62	114	149
2028	--	62	112	149
2029	--	59	108	144

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

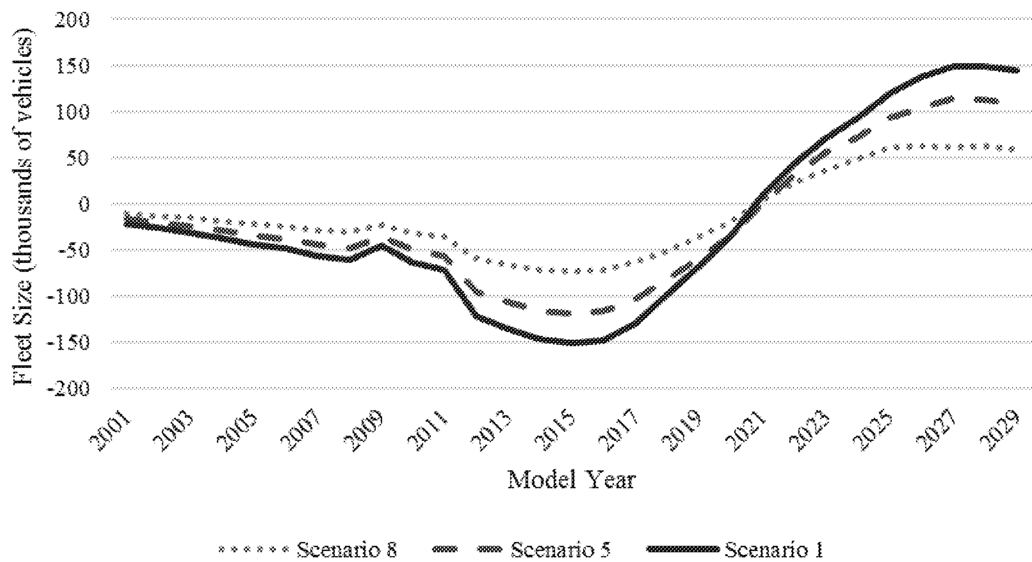
Table 8. Differences in Number of Vehicles (% Change) Compared to Augural Standards Baseline by Model Year in Calendar Year 2030

Model Year	Augural Standards	Scenario 8	Scenario 5	Scenario 1
2001	--	-2.85%	-4.46%	-5.74%
2002	--	-2.80%	-4.38%	-5.64%
2003	--	-2.74%	-4.29%	-5.52%
2004	--	-2.67%	-4.18%	-5.37%
2005	--	-2.58%	-4.06%	-5.20%
2006	--	-2.48%	-3.91%	-4.99%
2007	--	-2.36%	-3.73%	-4.75%
2008	--	-2.22%	-3.52%	-4.47%
2009	--	-2.05%	-3.27%	-4.14%
2010	--	-1.88%	-3.00%	-3.81%
2011	--	-1.70%	-2.73%	-3.47%
2012	--	-1.50%	-2.42%	-3.07%
2013	--	-1.30%	-2.10%	-2.68%
2014	--	-1.10%	-1.79%	-2.27%
2015	--	-0.91%	-1.48%	-1.88%
2016	--	-0.73%	-1.18%	-1.50%
2017	--	-0.55%	-0.90%	-1.13%
2018	--	-0.41%	-0.66%	-0.79%
2019	--	-0.27%	-0.45%	-0.51%
2020	--	-0.13%	-0.24%	-0.25%
2021	--	0.04%	0.01%	0.07%
2022	--	0.14%	0.20%	0.28%
2023	--	0.23%	0.34%	0.44%
2024	--	0.29%	0.43%	0.56%
2025	--	0.35%	0.53%	0.68%
2026	--	0.35%	0.57%	0.76%
2027	--	0.33%	0.61%	0.80%
2028	--	0.33%	0.59%	0.79%
2029	--	0.31%	0.56%	0.75%

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

Figure 4 illustrates the changes in 2030, showing differences in number of vehicles by model year compared to the augural standards baseline. The alternative standards have the effect of making the age distribution "newer" due to two effects: (a) more new vehicles are in service due to increases in new vehicle sales; and (b) fewer existing vehicles are in service through the effect of the higher new vehicle prices on increasing scrappage rates for used vehicles.

Figure 4. Differences in Fleet Effects Compared to Augural Standards Baseline by Model Year, for Calendar Year 2030 (all vehicles)



C. Impacts on Vehicle Miles Traveled (VMT)

The CAFE alternatives can affect VMT in three major ways. First, new sales and scrappage effects combine to affect the age composition of the fleet, with newer vehicles generally driving more miles in a year than older vehicles. Second, the balance of sales and scrappage effects can affect the size of the fleet, which would affect the level of VMT. Finally, and most significantly, CAFE alternatives affect VMT for vehicles subject to the alternative standards through the "rebound effect," i.e., the effect of changes in the per-mile cost of driving (via changes in fuel economy) on the number of miles traveled.

Table 9 provides estimates of total VMT in each CAFE alternative or every five years from 2020 to 2050. We emphasize that these values only include miles driven for motor vehicles in model years up to MY 2029. Thus, the total VMT decreases in later years as we focus on an increasingly small subset of the total fleet.

Table 9. VMT (billions) for Select Calendar Years

Calendar Year	Augural standards	Scenario 8	Scenario 5	Scenario 1
2020	2,798.1	2,797.0	2,796.4	2,794.8
2025	2,923.1	2,915.4	2,911.0	2,903.5
2030	2,807.6	2,795.4	2,786.7	2,773.0
2035	1,687.9	1,680.4	1,674.8	1,665.4
2040	786.7	783.7	781.3	776.7
2045	256.0	254.9	254.1	252.5
2050	70.6	70.4	70.1	69.6

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

Table 10 and Table 11 show the effects of the three alternatives on the VMT over time by calculating the differences in the VMT relative to the augural standards baseline levels, both in absolute and percentage terms. VMT is highest under the augural standards and lowest under Alternative 1 in all calendar years. In terms of percentage increases, in 2030, for example, the 34.5 billion miles reduction in VMT for Alternative 1 would represent about a 1.23% decrease in VMT relative to the augural standards.

Table 10. Differences in VMT (billions) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Augural Standards	Scenario 8	Scenario 5	Scenario 1
2020	--	-1.1	-1.7	-3.3
2025	--	-7.7	-12.1	-19.5
2030	--	-12.1	-20.8	-34.5
2035	--	-7.4	-13.1	-22.4
2040	--	-3.0	-5.4	-9.9
2045	--	-1.1	-1.9	-3.5
2050	--	-0.2	-0.5	-1.0

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

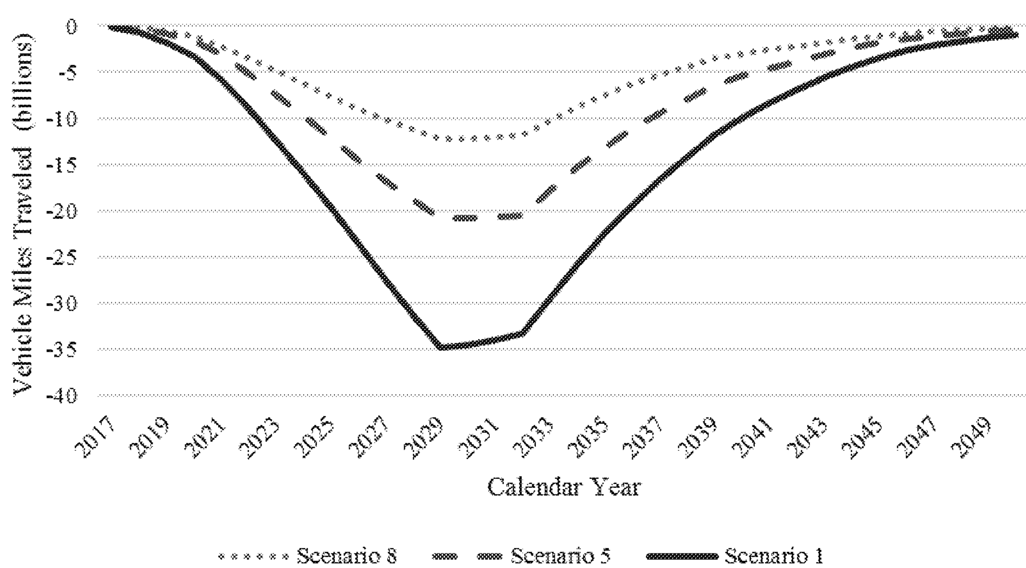
Table 11. Differences in VMT (% Change) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Augural Standards	Scenario 8	Scenario 5	Scenario 1
2020	--	-0.04%	-0.06%	-0.12%
2025	--	-0.26%	-0.41%	-0.67%
2030	--	-0.43%	-0.74%	-1.23%
2035	--	-0.44%	-0.78%	-1.33%
2040	--	-0.38%	-0.69%	-1.26%
2045	--	-0.42%	-0.72%	-1.35%
2050	--	-0.31%	-0.64%	-1.38%

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

Figure 5 provides a graphical illustration of the changes in U.S. VMT under the alternative CAFE standards, relative to VMT under the Baseline scenario in each calendar year. This graph shows that the less stringent CAFE standards (relative to the augural standards) are estimated to lead to decreases in VMT.

Figure 5. Change in Vehicles Miles of Travel (VMT) (Millions of Miles/Year)



Note: Values includes passenger cars and light trucks.
Source: NERA and Trinity calculations as explained in text.

D. Impacts on Fuel Consumption

The alternative CAFE standards would affect motor fuel consumption through various effects including: (a) effects on the fuel economy of the new vehicles subject to the standards as well as on the numbers of new vehicles sold; (b) effects on the numbers of existing vehicles on the road; and (c) through the rebound effect, changes in the VMT of the new vehicles whose fuel economy would be lower. As seen above, VMT is lower for each of the less-stringent CAFE alternatives compared to the augural standards. The effects on fuel consumption, however, will also depend on the effects on the fuel economy of the vehicles traveling those miles.

Table 12 shows estimates of the motor fuel consumed (cumulative for gasoline, diesel, and E85) for the three CAFE alternatives and the augural standards in five-year intervals from 2020 to 2050. We emphasize again that these estimates only include fuel consumption for model years up to MY 2029, and thus the total fuel consumption decreases substantially over time as the estimates cover an increasingly small subset of the fleet.

Table 12. Gallons of Motor Fuel Consumption (billions) for Select Calendar Years

Calendar Year	Augural Standards	Scenario 8	Scenario 5	Scenario 1
2020	116.3	116.4	116.4	116.6
2025	104.1	104.7	105.2	106.1
2030	89.3	90.5	91.3	92.9
2035	51.3	52.2	52.8	53.9
2040	23.4	23.9	24.3	24.9
2045	7.8	8.0	8.1	8.3
2050	2.2	2.3	2.3	2.4

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

Table 13 and Table 14 shows the effects of the three alternatives on motor fuel consumption in select calendar years by calculating the differences in gallons of fuel consumed relative to the augural standards baseline levels, both in absolute and percentage terms. Fuel consumption is greatest under Alternative 1, reflecting the fact that Alternative 1 leads to the lowest fuel economy (i.e., lowest MPG).

Table 13. Increases in Motor Fuel Consumption (billions of gallons) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Augural Standards	Scenario 8	Scenario 5	Scenario 1
2020	--	0.1	0.1	0.4
2025	--	0.7	1.1	2.1
2030	--	1.2	2.0	3.6
2035	--	0.9	1.5	2.6
2040	--	0.5	0.8	1.4
2045	--	0.2	0.3	0.5
2050	--	0.0	0.1	0.2

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

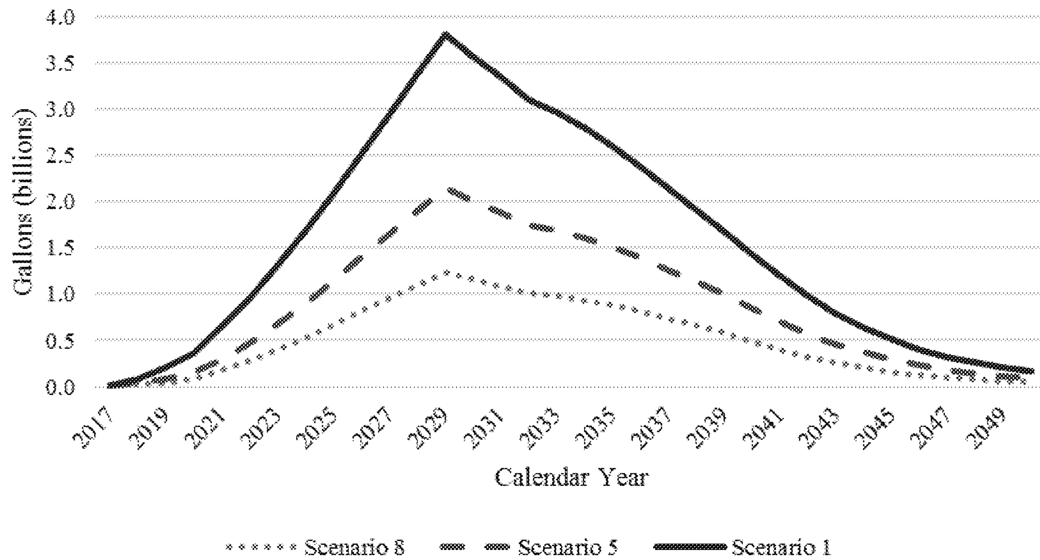
Table 14. Increases in Motor Fuel Consumption (% Change) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Augural standards	Scenario 8	Scenario 5	Scenario 1
2020	--	0.07%	0.13%	0.31%
2025	--	0.64%	1.09%	2.00%
2030	--	1.30%	2.25%	4.00%
2035	--	1.71%	2.94%	5.06%
2040	--	2.09%	3.61%	6.09%
2045	--	2.05%	3.73%	6.54%
2050	--	2.24%	4.15%	7.45%

Note: Results include both passenger cars and light trucks.
Source: NERA calculations as explained in text.

Figure 6 provides a graphical illustration of the estimated increases in motor fuel consumption for the three alternative CAFE standards over time. Fuel consumption increases for all three alternatives relative to the levels under the augural standards, reflecting the lower average MPG of the fleet. In 2029, estimated light-duty vehicle fuel consumption is 98 billion gallons under the augural standards—thus the 3.8 billion-gallon increase under Scenario 1 represents a 3.9 percent change. Among all uses of motor gasoline and diesel, which are projected to total 166 billion gallons in Annual Energy Outlook 2018 (EIA AEO 2018), this would represent a 1.29 percent change.

Figure 6. Increases in Motor Fuel Consumption Compared to Augural Standards Baseline by Calendar Year



Note: Gallon values include gasoline, diesel, and E85 fuel consumption.

E. Impacts on Greenhouse Gas Emissions

The alternative CAFE standards affect two sources of greenhouse gas (GHG) emissions.

1. *Tailpipe emissions.* The alternative standards would impact tailpipe emissions through the changes in the age composition of the vehicle fleet (i.e., older vehicles are less fuel-efficient) and as well as through changes in VMT (i.e., increased VMT leads to greater emissions). We develop estimates of tailpipe emissions using the MOVES Model.

2. *Upstream emissions.* The alternative standards would impact upstream emissions through changes in demand for petroleum-based fuels. We develop estimates of the upstream emissions using the upstream emissions factors (emissions/gallon) used by NHTSA/EPA in the PRIA, which are based on the GREET Model developed by the Argonne National Laboratory. The upstream emissions factors represent the emissions associated with fuel production including refining, distribution, and delivery.

Table 15 provides estimates of GHG emissions for the each of the four CAFE scenarios, including the augural standards baseline. We report tailpipe and upstream emissions separately. Our estimates of GHG emissions are expressed as CO_2 equivalents and include CO_2, N_2O, and CH_4 emissions.

Table 15. GHG Emissions (millions of metric tons) for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	998.5	997.9	997.7	997.0
	Upstream	347.4	347.7	347.8	348.5
	Total	**1,345.9**	**1,345.6**	**1,345.5**	**1,345.5**
2025	Tailpipe	880.9	890.0	894.7	920.1
	Upstream	285.1	286.9	288.2	290.8
	Total	**1,166.0**	**1,176.9**	**1,182.9**	**1,210.9**
2030	Tailpipe	737.4	756.3	771.1	823.9
	Upstream	241.3	244.4	246.8	251.0
	Total	**978.7**	**1,000.7**	**1,017.8**	**1,074.8**
2035	Tailpipe	422.3	438.0	450.0	489.5
	Upstream	138.7	141.1	142.8	145.7
	Total	**561.0**	**579.1**	**592.8**	**635.3**
2040	Tailpipe	192.7	201.8	209.0	230.9
	Upstream	63.6	64.9	65.9	67.4
	Total	**256.2**	**266.7**	**274.9**	**298.4**
2045	Tailpipe	64.6	67.6	70.2	78.5
	Upstream	21.1	21.5	21.9	22.5
	Total	**85.7**	**89.1**	**92.1**	**101.0**
2050	Tailpipe	18.4	19.3	20.1	22.8
	Upstream	5.9	6.1	6.2	6.4
	Total	**24.4**	**25.3**	**26.2**	**29.2**

Note: Results include both passenger cars and light trucks. GHG emissions presented as CO_2 equivalents and include CO_2, N_2O, and CH_4 emissions.
Source: NERA/Trinity calculations as explained in text.

Table 16 and Table 17 provides estimates of the GHG emissions for each of the three alternative standards relative to the augural standards baseline, including the estimated differences and the differences expressed as a percentage of augural standards.

Table 16. Differences in GHG Emissions (millions of metric tons) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	-0.6	-0.8	-1.5
	Upstream	--	0.2	0.4	1.1
	Total	--	**-0.3**	**-0.4**	**-0.5**
2025	Tailpipe	--	9.0	13.8	39.2
	Upstream	--	1.8	3.1	5.7
	Total	--	**10.9**	**16.9**	**44.9**
2030	Tailpipe	--	18.9	33.7	86.5
	Upstream	--	3.1	5.4	9.7
	Total	--	**22.0**	**39.1**	**96.1**
2035	Tailpipe	--	15.6	27.7	67.2
	Upstream	--	2.4	4.1	7.0
	Total	--	**18.0**	**31.8**	**74.2**
2040	Tailpipe	--	9.1	16.4	38.3
	Upstream	--	1.3	2.3	3.9
	Total	--	**10.5**	**18.7**	**42.1**
2045	Tailpipe	--	2.9	5.6	13.9
	Upstream	--	0.4	0.8	1.4
	Total	--	**3.4**	**6.4**	**15.2**
2050	Tailpipe	--	0.8	1.6	4.4
	Upstream	--	0.1	0.2	0.4
	Total	--	**1.0**	**1.9**	**4.8**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

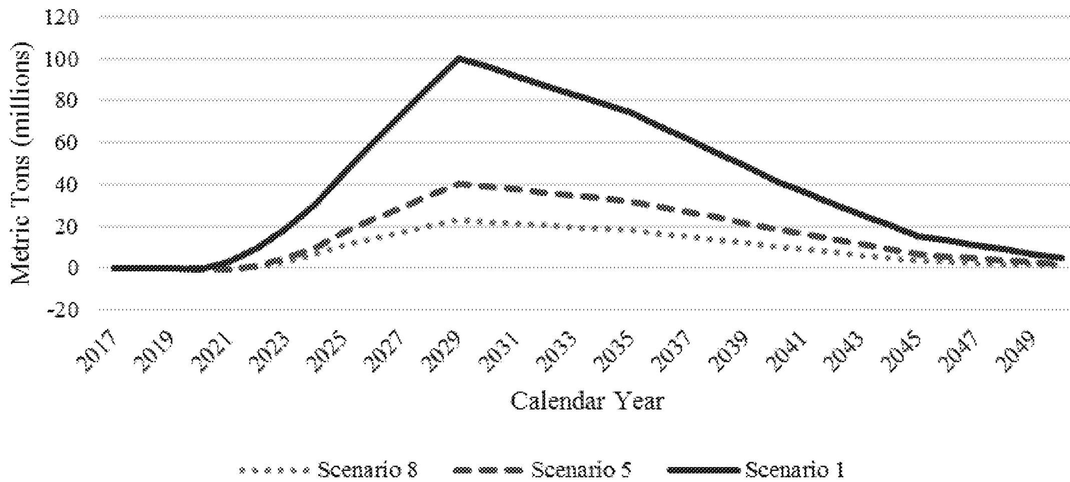
Table 17. Differences in GHG Emissions (% Change) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	-0.06%	-0.08%	-0.15%
	Upstream	--	0.07%	0.12%	0.31%
	Total	--	**-0.02%**	**-0.03%**	**-0.04%**
2025	Tailpipe	--	1.03%	1.56%	4.45%
	Upstream	--	0.64%	1.09%	2.00%
	Total	--	**0.93%**	**1.45%**	**3.85%**
2030	Tailpipe	--	2.56%	4.56%	11.72%
	Upstream	--	1.30%	2.25%	4.01%
	Total	--	**2.25%**	**3.99%**	**9.82%**
2035	Tailpipe	--	3.71%	6.56%	15.91%
	Upstream	--	1.72%	2.95%	5.07%
	Total	--	**3.21%**	**5.67%**	**13.23%**
2040	Tailpipe	--	4.74%	8.51%	19.86%
	Upstream	--	2.10%	3.62%	6.10%
	Total	--	**4.08%**	**7.29%**	**16.45%**
2045	Tailpipe	--	4.55%	8.64%	21.43%
	Upstream	--	2.05%	3.73%	6.55%
	Total	--	**3.94%**	**7.43%**	**17.77%**
2050	Tailpipe	--	4.48%	8.86%	23.81%
	Upstream	--	2.24%	4.15%	7.46%
	Total	--	**3.93%**	**7.71%**	**19.82%**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Figure 7 illustrates the estimated changes in GHG emissions (expressed as CO_2 equivalents) of the three alternative CAFE standards we evaluate over the analysis period. (As noted, the results are only for model years up to MY 2029.) The GHG emissions increase for all three alternatives, reflecting the increase in fuel consumption due to the less fuel-efficient fleets under the less-stringent CAFE standards. In 2029—the year with the greatest impact—the estimated total CO_{2eq} emissions for the light fleet are 1.08 billion metric tons; thus the 99.7 million metric ton increase under Scenario 1 represents a 9.3 percent change in light fleet emissions. The change in CO_{2eq} emissions in 2029 would represent a 2.0 percent change in U.S. economy wide emissions, based upon a projection of 5.1 billion metric tons in 2029 (EIA AEO 2018).

Figure 7. Differences in GHG Emissions (CO_{2eq}) relative to Augural Standards Baseline by Calendar Year



Note: GHG emissions presented as CO_2 equivalents and include CO_2, N_2O, and CH_4 emissions.

F. Impacts on Criteria Pollutant Emissions

The alternative CAFE standards would result in changes in criteria emissions, which include emissions for which air quality criteria have been set as well as precursor emissions, i.e., emissions that influence the level of criteria pollutants. The MOVES Model is used to estimate effects on tailpipe emissions. The tailpipe emissions from MOVES are supplemented by estimates of the effects of changes in upstream emissions based on upstream factors used by NHTSA/EPA for the PRIA developed from the GREET Model. We develop estimates for five criteria pollutants:

- Nitrogen oxides (NOx), both a criteria pollutant and a precursor for ambient ozone and particulate matter;
- Volatile organic compounds (VOC), a precursor pollutant for ambient ozone;
- Particulate matter ($PM_{2.5}$), a criteria pollutant;
- Sulfur dioxide (SO_2), a criteria pollutant and a precursor for $PM_{2.5}$; and
- Carbon monoxide, a criteria pollutant;

1. Impacts on NO_X Emissions

Table 18 provides our estimates of NO_X emissions for each of the alternative scenarios as well as for the augural standards baseline.

Table 18. NO_X Emissions (thousands of metric tons) for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	733.1	732.8	732.0	730.7
	Upstream	208.9	209.0	209.1	209.5
	Total	**942.0**	**941.9**	**941.2**	**940.2**
2025	Tailpipe	414.6	411.4	409.8	407.9
	Upstream	180.2	181.3	182.2	183.8
	Total	**594.8**	**592.8**	**591.9**	**591.7**
2030	Tailpipe	264.7	262.3	260.8	259.3
	Upstream	155.3	157.3	158.8	161.5
	Total	**420.0**	**419.6**	**419.6**	**420.8**
2035	Tailpipe	157.3	156.6	156.1	155.6
	Upstream	88.6	90.1	91.2	93.1
	Total	**245.9**	**246.7**	**247.3**	**248.7**
2040	Tailpipe	78.6	78.5	78.4	78.3
	Upstream	39.5	40.4	41.0	41.9
	Total	**118.1**	**118.8**	**119.4**	**120.3**
2045	Tailpipe	29.2	29.1	29.1	29.1
	Upstream	13.3	13.5	13.8	14.1
	Total	**42.4**	**42.7**	**42.9**	**43.3**
2050	Tailpipe	8.5	8.5	8.5	8.5
	Upstream	3.8	3.9	4.0	4.1
	Total	**12.3**	**12.4**	**12.5**	**12.6**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Table 19 and Table 20 provide our estimates of NO_X emissions for each of the alternative scenarios relative to the augural standards baseline, both in absolute and percentage terms.

Table 19. Differences in NO_X Emissions (thousands of metric tons) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	-0.3	-1.1	-2.4
	Upstream	--	0.1	0.3	0.7
	Total	--	**-0.1**	**-0.8**	**-1.7**
2025	Tailpipe	--	-3.2	-4.9	-6.7
	Upstream	--	1.2	2.0	3.6
	Total	--	**-2.0**	**-2.9**	**-3.1**
2030	Tailpipe	--	-2.4	-3.9	-5.4
	Upstream	--	2.0	3.5	6.2
	Total	--	**-0.4**	**-0.4**	**0.8**
2035	Tailpipe	--	-0.7	-1.2	-1.7
	Upstream	--	1.5	2.6	4.5
	Total	--	**0.8**	**1.4**	**2.8**
2040	Tailpipe	--	-0.1	-0.2	-0.2
	Upstream	--	0.8	1.4	2.4
	Total	--	**0.7**	**1.3**	**2.2**
2045	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	0.3	0.5	0.9
	Total	--	**0.2**	**0.5**	**0.8**
2050	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	0.1	0.2	0.3
	Total	--	**0.1**	**0.2**	**0.3**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

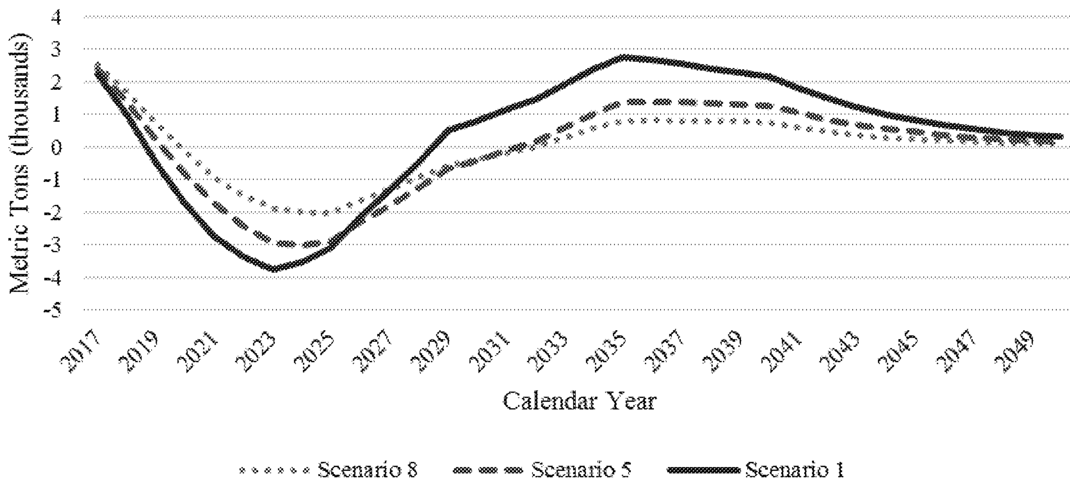
Table 20. Differences in NO_X Emissions (% Change) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	-0.04%	-0.15%	-0.33%
	Upstream	--	0.07%	0.12%	0.31%
	Total	--	**-0.01%**	**-0.09%**	**-0.18%**
2025	Tailpipe	--	-0.77%	-1.17%	-1.61%
	Upstream	--	0.64%	1.10%	2.01%
	Total	--	**-0.34%**	**-0.49%**	**-0.52%**
2030	Tailpipe	--	-0.91%	-1.48%	-2.04%
	Upstream	--	1.29%	2.25%	3.99%
	Total	--	**-0.10%**	**-0.10%**	**0.19%**
2035	Tailpipe	--	-0.44%	-0.77%	-1.07%
	Upstream	--	1.70%	2.92%	5.03%
	Total	--	**0.33%**	**0.56%**	**1.13%**
2040	Tailpipe	--	-0.10%	-0.21%	-0.30%
	Upstream	--	2.07%	3.58%	6.05%
	Total	--	**0.63%**	**1.06%**	**1.82%**
2045	Tailpipe	--	-0.11%	-0.12%	-0.11%
	Upstream	--	2.02%	3.70%	6.51%
	Total	--	**0.56%**	**1.08%**	**1.96%**
2050	Tailpipe	--	0.22%	0.30%	0.39%
	Upstream	--	2.23%	4.13%	7.44%
	Total	--	**0.84%**	**1.48%**	**2.57%**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Figure 8 provides a graphical presentation of the changes over time in NO_X emissions under the three alternative CAFE standards. The changes in NO_X emissions are due both to changes in tailpipe emissions and changes in upstream emissions. NO_X tailpipe emissions are lower for all three alternatives in most years, reflecting the accelerated scrappage of older vehicles under the less-stringent standards. In contrast, NO_X upstream emissions increase because of increases in gasoline transportation, distribution, and storage under the less-stringent standards. For the alternative standards, the net result is a pattern of net NO_X emissions that are lower relative to the augural standards baseline in earlier years (as tailpipe emissions reductions exceed upstream emissions increases) and higher in the later years (as upstream emissions increases exceed tailpipe emissions reductions). As with all effects, by the end of the period the net changes are small because MY 2029 and earlier motor vehicles become a small part of the vehicle fleet.

Figure 8. Differences in NO_X Emissions relative to Augural Standards Baseline by Calendar Year



2. Impacts on VOC Emissions

Table 30 provides our estimates of VOC emissions for each of the alternative scenarios as well as for the augural standards baseline. Note that due to a limitation of the MOVES model these estimates do not include changes in evaporative tailpipe VOC emissions. Note that the NHTSA/EPA PRIA notes that the agencies' analysis also does not include estimates of the evaporative emission from light-duty vehicles.[11]

[11] See p. 1303 of NHTSA/EPA PRIA (2018b)

Table 21. VOC Emissions (thousands of metric tons) for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	496.4	496.8	496.3	495.6
	Upstream	329.1	329.3	329.5	330.1
	Total	**825.5**	**826.1**	**825.8**	**825.7**
2025	Tailpipe	316.6	314.7	313.7	312.7
	Upstream	305.0	306.9	308.3	311.1
	Total	**621.6**	**621.7**	**622.0**	**623.7**
2030	Tailpipe	213.3	211.7	210.7	209.9
	Upstream	262.6	265.9	268.5	273.0
	Total	**475.8**	**477.7**	**479.2**	**483.0**
2035	Tailpipe	130.0	129.6	129.2	128.9
	Upstream	150.7	153.2	155.1	158.3
	Total	**280.7**	**282.8**	**284.3**	**287.2**
2040	Tailpipe	66.5	66.5	66.4	66.4
	Upstream	68.6	70.1	71.1	72.8
	Total	**135.1**	**136.5**	**137.5**	**139.2**
2045	Tailpipe	25.0	24.9	24.9	24.9
	Upstream	22.9	23.4	23.8	24.4
	Total	**47.9**	**48.3**	**48.7**	**49.4**
2050	Tailpipe	7.5	7.5	7.5	7.5
	Upstream	6.5	6.6	6.8	7.0
	Total	**14.0**	**14.2**	**14.3**	**14.5**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Table 22 and Table 23 provides our estimates of VOC emissions for each of the alternative scenarios relative to the augural standards baseline, expressed as differences and percentage differences.

Table 22. VOC Emissions (thousands of metric tons) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	0.4	-0.1	-0.8
	Upstream	--	0.2	0.4	1.0
	Total	--	**0.6**	**0.3**	**0.2**
2025	Tailpipe	--	-1.9	-2.9	-3.9
	Upstream	--	1.9	3.3	6.1
	Total	--	**0.1**	**0.4**	**2.1**
2030	Tailpipe	--	-1.5	-2.5	-3.3
	Upstream	--	3.4	5.9	10.5
	Total	--	**1.9**	**3.4**	**7.1**
2035	Tailpipe	--	-0.5	-0.8	-1.1
	Upstream	--	2.6	4.4	7.6
	Total	--	**2.1**	**3.6**	**6.5**
2040	Tailpipe	--	0.0	-0.1	-0.1
	Upstream	--	1.4	2.5	4.2
	Total	--	**1.4**	**2.4**	**4.0**
2045	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	0.5	0.9	1.5
	Total	--	**0.4**	**0.8**	**1.5**
2050	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	0.1	0.3	0.5
	Total	--	**0.2**	**0.3**	**0.5**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

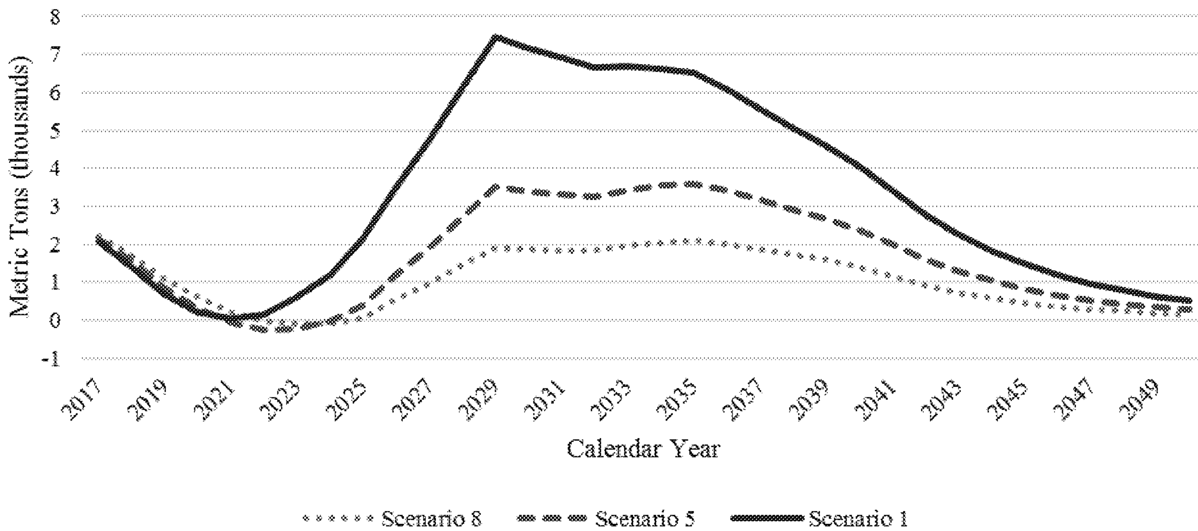
Table 23. VOC Emissions (% Change) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	0.08%	-0.01%	-0.16%
	Upstream	--	0.07%	0.12%	0.31%
	Total	--	**0.07%**	**0.04%**	**0.02%**
2025	Tailpipe	--	-0.59%	-0.92%	-1.25%
	Upstream	--	0.64%	1.09%	1.99%
	Total	--	**0.01%**	**0.06%**	**0.34%**
2030	Tailpipe	--	-0.72%	-1.18%	-1.57%
	Upstream	--	1.29%	2.25%	4.00%
	Total	--	**0.39%**	**0.71%**	**1.50%**
2035	Tailpipe	--	-0.36%	-0.64%	-0.85%
	Upstream	--	1.70%	2.93%	5.05%
	Total	--	**0.75%**	**1.28%**	**2.32%**
2040	Tailpipe	--	-0.04%	-0.12%	-0.18%
	Upstream	--	2.08%	3.60%	6.07%
	Total	--	**1.04%**	**1.77%**	**2.99%**
2045	Tailpipe	--	-0.07%	-0.07%	-0.04%
	Upstream	--	2.03%	3.71%	6.52%
	Total	--	**0.94%**	**1.74%**	**3.10%**
2050	Tailpipe	--	0.25%	0.34%	0.44%
	Upstream	--	2.23%	4.13%	7.44%
	Total	--	**1.17%**	**2.10%**	**3.69%**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Figure 9 provides a graphical presentation of the changes over time in VOC emissions under the three alternative CAFE standards. Tailpipe VOC emissions are lower for all three alternatives in most years, reflecting the accelerated scrappage of older vehicles under the less-stringent standards. The upstream VOC emissions are greater for all three alternatives, reflecting the increase in fuel consumption and associated upstream emissions due to the alternative standards. Combined, net VOC emissions are greater for all three alternatives after calendar year 2025, as the increases in upstream emissions exceed reductions in tailpipe emissions from scrappage effects.

Figure 9. Differences in VOC Emissions relative to Augural Standards Baseline by Calendar Year



3. Impacts on Particulate Matter Emissions

Table 24 provides our estimates of $PM_{2.5}$ emissions for each of the alternative scenarios as well as for the augural standards baseline.

Table 24. $PM_{2.5}$ Emissions (metric tons) for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	16,752.1	16,738.6	16,727.0	16,706.3
	Upstream	16,784.6	16,796.3	16,805.3	16,836.9
	Total	**33,536.8**	**33,534.9**	**33,532.3**	**33,543.2**
2025	Tailpipe	13,410.2	13,333.1	13,293.5	13,245.8
	Upstream	13,524.3	13,610.9	13,672.4	13,795.6
	Total	**26,934.5**	**26,944.0**	**26,965.9**	**27,041.4**
2030	Tailpipe	10,802.9	10,716.9	10,661.5	10,601.6
	Upstream	11,688.5	11,839.0	11,951.1	12,155.4
	Total	**22,491.4**	**22,555.9**	**22,612.6**	**22,757.0**
2035	Tailpipe	7,192.5	7,155.5	7,130.1	7,104.2
	Upstream	6,656.1	6,769.0	6,850.4	6,991.2
	Total	**13,848.6**	**13,924.4**	**13,980.5**	**14,095.4**
2040	Tailpipe	3,843.1	3,837.9	3,833.1	3,828.1
	Upstream	2,997.4	3,059.4	3,104.7	3,178.7
	Total	**6,840.5**	**6,897.3**	**6,937.9**	**7,006.8**
2045	Tailpipe	1,554.8	1,553.4	1,553.5	1,553.7
	Upstream	1,006.5	1,026.9	1,043.8	1,072.0
	Total	**2,561.3**	**2,580.3**	**2,597.3**	**2,625.7**
2050	Tailpipe	489.6	490.6	491.2	491.7
	Upstream	288.1	294.6	300.1	309.6
	Total	**777.7**	**785.1**	**791.2**	**801.3**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Table 25 and Table 26 provide our estimates of $PM_{2.5}$ emissions for each of the alternative scenarios relative to the augural standards baseline.

Table 25. $PM_{2.5}$ Emissions (metric tons) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	-13.6	-25.1	-45.9
	Upstream	--	11.7	20.7	52.2
	Total	--	**-1.9**	**-4.5**	**6.4**
2025	Tailpipe	--	-77.1	-116.8	-164.4
	Upstream	--	86.7	148.2	271.3
	Total	--	**9.5**	**31.4**	**106.9**
2030	Tailpipe	--	-86.0	-141.4	-201.3
	Upstream	--	150.5	262.6	466.8
	Total	--	**64.5**	**121.2**	**265.6**
2035	Tailpipe	--	-37.0	-62.4	-88.2
	Upstream	--	112.8	194.3	335.1
	Total	--	**75.8**	**131.9**	**246.8**
2040	Tailpipe	--	-5.2	-10.0	-15.0
	Upstream	--	62.1	107.4	181.4
	Total	--	**56.9**	**97.4**	**166.4**
2045	Tailpipe	--	-1.4	-1.3	-1.1
	Upstream	--	20.4	37.3	65.5
	Total	--	**19.0**	**36.0**	**64.4**
2050	Tailpipe	--	1.0	1.6	2.2
	Upstream	--	6.4	11.9	21.4
	Total	--	**7.4**	**13.5**	**23.6**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

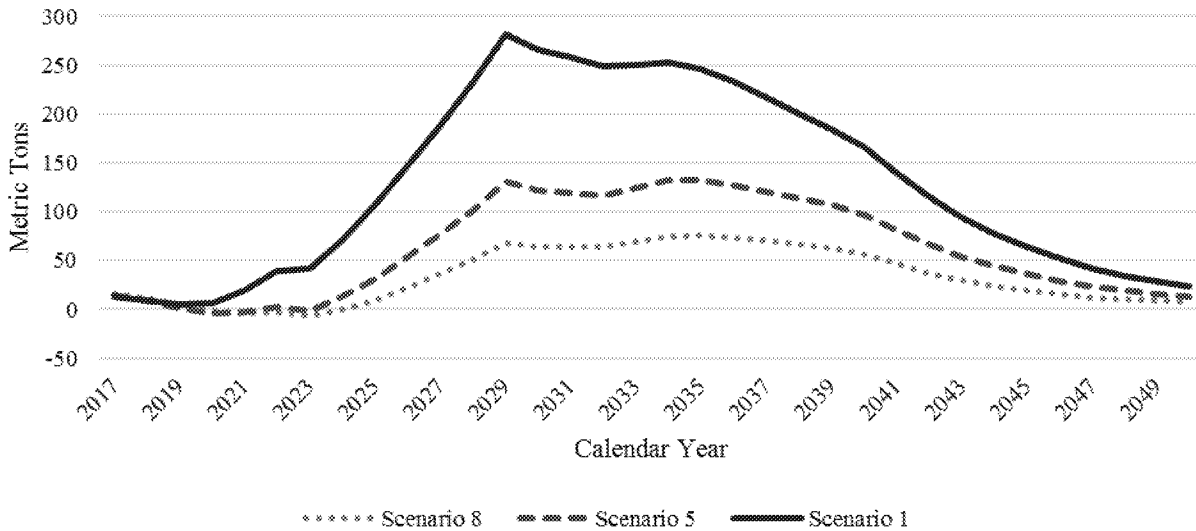
Table 26. $PM_{2.5}$ Emissions (% Change) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	-0.08%	-0.15%	-0.27%
	Upstream	--	0.07%	0.12%	0.31%
	Total	--	**-0.01%**	**-0.01%**	**0.02%**
2025	Tailpipe	--	-0.58%	-0.87%	-1.23%
	Upstream	--	0.64%	1.10%	2.01%
	Total	--	**0.04%**	**0.12%**	**0.40%**
2030	Tailpipe	--	-0.80%	-1.31%	-1.86%
	Upstream	--	1.29%	2.25%	3.99%
	Total	--	**0.29%**	**0.54%**	**1.18%**
2035	Tailpipe	--	-0.51%	-0.87%	-1.23%
	Upstream	--	1.69%	2.92%	5.03%
	Total	--	**0.55%**	**0.95%**	**1.78%**
2040	Tailpipe	--	-0.13%	-0.26%	-0.39%
	Upstream	--	2.07%	3.58%	6.05%
	Total	--	**0.83%**	**1.42%**	**2.43%**
2045	Tailpipe	--	-0.09%	-0.08%	-0.07%
	Upstream	--	2.02%	3.70%	6.51%
	Total	--	**0.74%**	**1.40%**	**2.51%**
2050	Tailpipe	--	0.20%	0.32%	0.44%
	Upstream	--	2.23%	4.13%	7.44%
	Total	--	**0.95%**	**1.74%**	**3.03%**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Figure 10 provides a graphical presentation of the changes over time in $PM_{2.5}$ emissions under the three alternative CAFE standards. The tailpipe $PM_{2.5}$ emissions are lower for all three alternatives in most years, reflecting the accelerated scrappage of older vehicles under the less-stringent standards. The upstream emissions are greater for all three alternatives, reflecting the increase in fuel consumption and associated fuel development emissions due to the alternative standards. The net impact on emissions indicates that the effects due to changes in fuel demand outweigh tailpipe $PM_{2.5}$ emissions impacts due to fleet age composition.

Figure 10. Differences in $PM_{2.5}$ Emissions relative to Augural Standards Baseline by Calendar Year



4. Impacts on SO_2 Emissions

Table 27 provides our estimates of SO_2 emissions for each of the alternative scenarios as well as for the augural standards baseline.

Table 27. SO_2 Emissions (metric tons) for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	6.5	6.5	6.5	6.5
	Upstream	186.8	186.9	187.0	187.4
	Total	**193.3**	**193.5**	**193.6**	**193.9**
2025	Tailpipe	5.8	5.8	5.8	5.8
	Upstream	130.5	131.3	131.9	133.1
	Total	**136.3**	**137.1**	**137.7**	**138.9**
2030	Tailpipe	4.9	4.8	4.8	4.8
	Upstream	112.5	113.9	115.0	117.0
	Total	**117.3**	**118.8**	**119.8**	**121.8**
2035	Tailpipe	2.8	2.8	2.8	2.8
	Upstream	63.8	64.9	65.7	67.0
	Total	**66.6**	**67.7**	**68.5**	**69.8**
2040	Tailpipe	1.3	1.3	1.3	1.3
	Upstream	28.6	29.2	29.7	30.4
	Total	**29.9**	**30.5**	**30.9**	**31.6**
2045	Tailpipe	0.4	0.4	0.4	0.4
	Upstream	9.6	9.8	9.9	10.2
	Total	**10.0**	**10.2**	**10.4**	**10.6**
2050	Tailpipe	0.1	0.1	0.1	0.1
	Upstream	2.7	2.8	2.8	2.9
	Total	**2.9**	**2.9**	**3.0**	**3.1**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Table 28 and Table 29 provide our estimates of SO_2 emissions for each of the alternative scenarios as well as for the augural standards baseline.

Table 28. SO_2 Emissions (metric tons) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	0.1	0.2	0.6
	Total	--	**0.1**	**0.2**	**0.6**
2025	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	0.8	1.4	2.6
	Total	--	**0.8**	**1.4**	**2.6**
2030	Tailpipe	--	0.0	0.0	-0.1
	Upstream	--	1.4	2.5	4.5
	Total	--	**1.4**	**2.5**	**4.4**
2035	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	1.1	1.9	3.2
	Total	--	**1.1**	**1.8**	**3.2**
2040	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	0.6	1.0	1.7
	Total	--	**0.6**	**1.0**	**1.7**
2045	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	0.2	0.4	0.6
	Total	--	**0.2**	**0.4**	**0.6**
2050	Tailpipe	--	0.0	0.0	0.0
	Upstream	--	0.1	0.1	0.2
	Total	--	**0.1**	**0.1**	**0.2**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

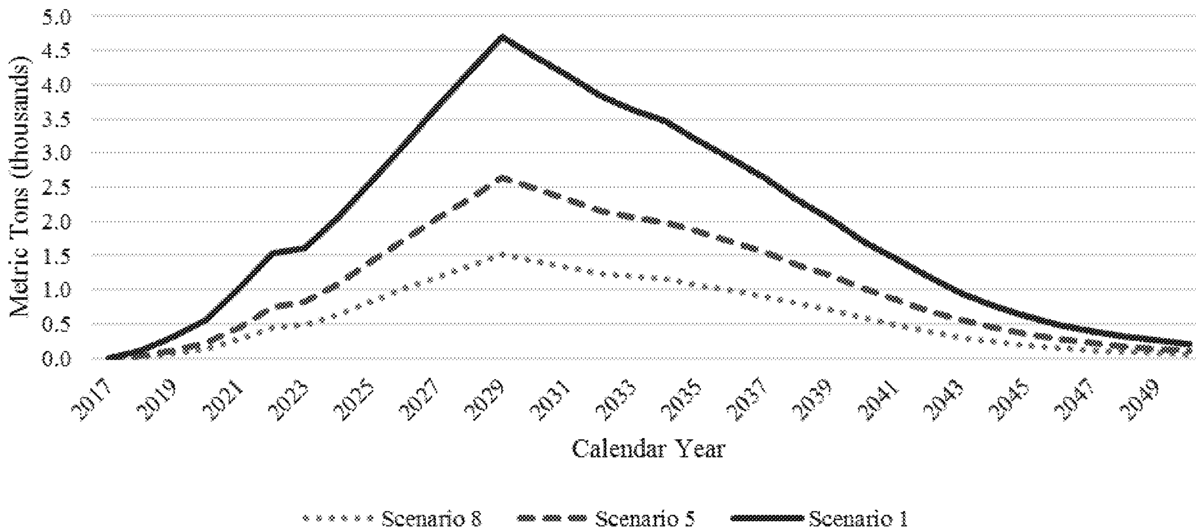
Table 29. SO_2 Emissions (% Change) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	-0.06%	-0.08%	-0.15%
	Upstream	--	0.07%	0.12%	0.31%
	Total	--	**0.06%**	**0.12%**	**0.29%**
2025	Tailpipe	--	-0.35%	-0.54%	-0.82%
	Upstream	--	0.64%	1.10%	2.01%
	Total	--	**0.60%**	**1.03%**	**1.89%**
2030	Tailpipe	--	-0.51%	-0.85%	-1.34%
	Upstream	--	1.29%	2.25%	3.99%
	Total	--	**1.21%**	**2.12%**	**3.77%**
2035	Tailpipe	--	-0.31%	-0.52%	-0.82%
	Upstream	--	1.69%	2.92%	5.03%
	Total	--	**1.61%**	**2.77%**	**4.79%**
2040	Tailpipe	--	-0.03%	-0.06%	-0.15%
	Upstream	--	2.07%	3.58%	6.05%
	Total	--	**1.98%**	**3.43%**	**5.78%**
2045	Tailpipe	--	-0.01%	0.06%	0.11%
	Upstream	--	2.02%	3.70%	6.51%
	Total	--	**1.94%**	**3.55%**	**6.23%**
2050	Tailpipe	--	0.18%	0.29%	0.40%
	Upstream	--	2.23%	4.13%	7.44%
	Total	--	**2.14%**	**3.97%**	**7.14%**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Figure 11 provides a graphical presentation of the changes over time in SO_2 emissions under the three alternative CAFE standards. Tailpipe SO_2 emissions are lower for all three alternatives in most years, reflecting the accelerated scrappage of older vehicles under the less-stringent standards. The upstream emissions are greater for all three alternatives, reflecting the increase in fuel consumption and associated upstream emissions due to the alternative standards. The net increase in emissions for all calendar years indicates that the upstream SO_2 impacts from changes in fuel demand outweigh the effects due to fleet age composition, as tailpipe emissions for SO_2 are relatively small.

Figure 11. Differences in SO_2 Emissions relative to Augural Standards Baseline by Calendar Year



5. Impacts on Carbon Monoxide Emissions

Table 21 provides our estimates of CO emissions for each of the alternative scenarios as well as for the augural standards baseline.

Table 30. CO Emissions (thousands of metric tons) for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	9,036.9	9,031.5	9,025.1	9,013.7
	Upstream	97.3	97.4	97.4	97.6
	Total	**9,134.2**	**9,128.9**	**9,122.5**	**9,111.3**
2025	Tailpipe	6,792.1	6,752.4	6,731.7	6,707.7
	Upstream	87.7	88.2	88.6	89.4
	Total	**6,879.8**	**6,840.7**	**6,820.4**	**6,797.1**
2030	Tailpipe	4,862.7	4,822.9	4,797.2	4,770.6
	Upstream	76.0	77.0	77.7	79.1
	Total	**4,938.7**	**4,899.9**	**4,874.9**	**4,849.7**
2035	Tailpipe	2,997.4	2,982.7	2,972.3	2,962.0
	Upstream	43.6	44.4	44.9	45.8
	Total	**3,041.0**	**3,027.1**	**3,017.2**	**3,007.8**
2040	Tailpipe	1,478.1	1,476.4	1,474.5	1,472.6
	Upstream	19.7	20.1	20.4	20.9
	Total	**1,497.9**	**1,496.5**	**1,494.9**	**1,493.6**
2045	Tailpipe	544.3	543.6	543.5	543.5
	Upstream	6.6	6.7	6.9	7.0
	Total	**550.9**	**550.3**	**550.4**	**550.5**
2050	Tailpipe	160.8	161.1	161.3	161.5
	Upstream	1.9	1.9	2.0	2.0
	Total	**162.7**	**163.1**	**163.3**	**163.5**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Table 31 and Table 32 provides our estimates of CO emissions for each of the alternative scenarios relative to the augural standards baseline.

Table 31. CO Emissions (thousands of metric tons) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	-5.4	-11.8	-23.2
	Upstream	--	0.1	0.1	0.3
	Total	--	**-5.4**	**-11.7**	**-22.9**
2025	Tailpipe	--	-39.7	-60.4	-84.4
	Upstream	--	0.6	1.0	1.8
	Total	--	**-39.2**	**-59.4**	**-82.7**
2030	Tailpipe	--	-39.8	-65.5	-92.0
	Upstream	--	1.0	1.7	3.0
	Total	--	**-38.8**	**-63.8**	**-89.0**
2035	Tailpipe	--	-14.6	-25.1	-35.4
	Upstream	--	0.7	1.3	2.2
	Total	--	**-13.9**	**-23.8**	**-33.2**
2040	Tailpipe	--	-1.8	-3.6	-5.5
	Upstream	--	0.4	0.7	1.2
	Total	--	**-1.4**	**-2.9**	**-4.3**
2045	Tailpipe	--	-0.7	-0.8	-0.8
	Upstream	--	0.1	0.2	0.4
	Total	--	**-0.6**	**-0.5**	**-0.3**
2050	Tailpipe	--	0.3	0.5	0.6
	Upstream	--	0.0	0.1	0.1
	Total	--	**0.4**	**0.5**	**0.8**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

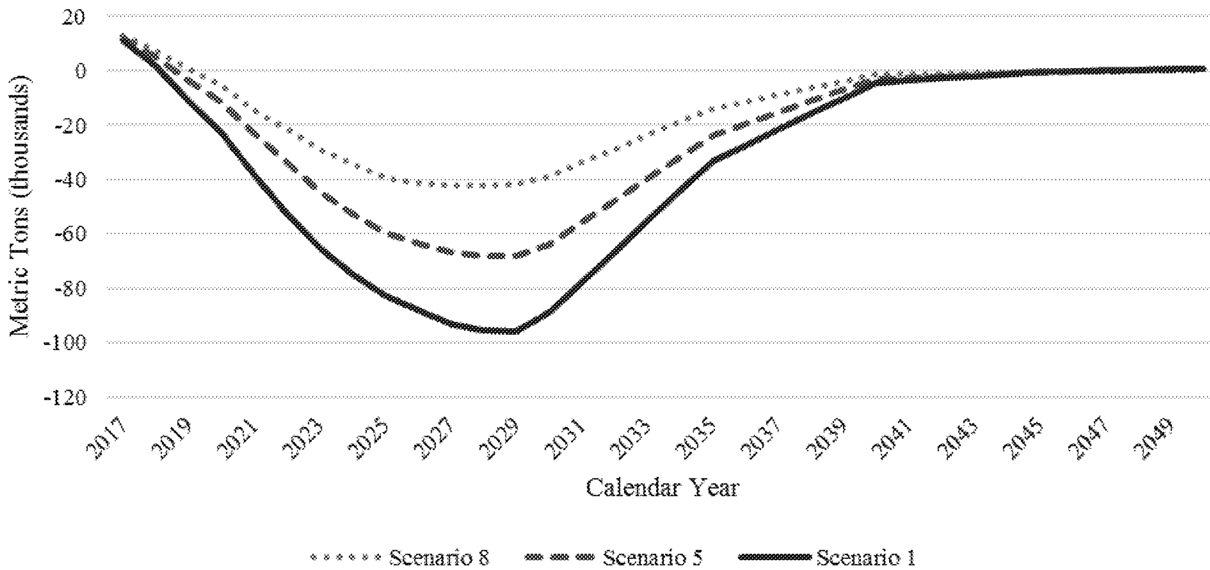
Table 32. CO Emissions (% Change) Compared to Augural Standards Baseline for Select Calendar Years

Calendar Year	Source	Augural Stds	Scenario 8	Scenario 5	Scenario 1
2020	Tailpipe	--	-0.06%	-0.13%	-0.26%
	Upstream	--	0.07%	0.12%	0.31%
	Total	--	**-0.06%**	**-0.13%**	**-0.25%**
2025	Tailpipe	--	-0.58%	-0.89%	-1.24%
	Upstream	--	0.64%	1.09%	2.00%
	Total	--	**-0.57%**	**-0.86%**	**-1.20%**
2030	Tailpipe	--	-0.82%	-1.35%	-1.89%
	Upstream	--	1.29%	2.25%	4.00%
	Total	--	**-0.79%**	**-1.29%**	**-1.80%**
2035	Tailpipe	--	-0.49%	-0.84%	-1.18%
	Upstream	--	1.70%	2.93%	5.04%
	Total	--	**-0.46%**	**-0.78%**	**-1.09%**
2040	Tailpipe	--	-0.12%	-0.24%	-0.37%
	Upstream	--	2.08%	3.59%	6.06%
	Total	--	**-0.09%**	**-0.19%**	**-0.29%**
2045	Tailpipe	--	-0.13%	-0.14%	-0.14%
	Upstream	--	2.03%	3.71%	6.52%
	Total	--	**-0.10%**	**-0.09%**	**-0.06%**
2050	Tailpipe	--	0.19%	0.29%	0.39%
	Upstream	--	2.23%	4.14%	7.44%
	Total	--	**0.22%**	**0.34%**	**0.48%**

Note: Results include both passenger cars and light trucks.
Source: NERA/Trinity calculations as explained in text.

Figure 9 provides a graphical presentation of the changes over time in CO emissions under the three alternative CAFE standards. The CO tailpipe emissions are lower for all three alternatives in most years, reflecting the accelerated scrappage of older vehicles under the less-stringent standards. The upstream emissions are greater for all three alternatives, reflecting the increase in fuel consumption and associated upstream emissions due to the alternative standards. The net impact on emissions indicates that the CO decreases due to fleet age composition outweigh the emissions increases due to changes in fuel demand.

Figure 12. Differences in CO Emissions relative to Augural Standards Baseline by Calendar Year



IV. Social Costs of Alternative CAFE Standards

This chapter uses the results of the fleet population, VMT, and emissions modeling summarized in the previous chapter, along with other parameters, [12] to develop estimates of the social costs of the three alternative CAFE standards. As with the social benefit estimates provided in the next chapter, we rely on sound cost-benefit methodology based on the existing academic literature (see, e.g., Boardman et al. 2011) and the relevant EPA guidelines (EPA 2014).

We include the following four social cost categories:

1. *New vehicle technology costs.* These costs include the costs of the technologies to achieve compliance with the various CAFE standards.
2. *Congestion costs.* Changes in VMT lead to changes in the congestion costs that motorists incur on the road.
3. *Noise costs.* Changes in VMT lead to changes in the noise levels that motorists experience.
4. *Crash costs.* Changes in the vehicle fleet and VMT lead to changes in fatal and non-fatal crash costs.

All values reported in this chapter and the next are present values over the period from 2017 to 2050 (in billions of 2016 dollars) as of January 1, 2017, based upon information for model years through MY 2029, using both 3% and 7% discount rates.

A. New Vehicle Technology Costs

This section assesses the social costs of the additional technologies adopted for new vehicles to achieve compliance with the CAFE standard alternatives, as estimated by Trinity using the latest version of the CAFE Model developed by the DOT. Technology costs represent the additional costs borne by consumers who pay for these technologies in the form of higher vehicle prices. Below, we discuss the methodology for estimating these costs. We then present estimates of the difference in technology costs for each of the three CAFE alternatives compared to the augural standards.

1. Methodology

CAFE standards lead automobile manufacturers to incorporate additional fuel-efficiency-enhancing technologies into their vehicles. The specific technologies adopted by manufacturers are estimated in the CAFE Model, which assumes that manufacturers minimize the effective cost of technology application on a group of vehicles. This minimization accounts for the cost of all potential technologies, the value to consumers of fuel savings due to the technologies, and the effects of non-compliance costs (CAFE fines). Note that the CAFE Model was adapted for this

[12] We rely upon many parameters developed by EPA and NHTSA, most of which are described in the PRIA. We have not developed independent assessments of these parameters. The same caveat applies to parameters discussed in this chapter and the next (and in appendices) related to valuation of congestion, noise, crash costs, compliance costs, petroleum market externalities, GHG emissions, and conventional pollutant emissions.

study by Trinity. For information on the CAFE Model and its implementation for this study, see Appendix A.

We apply the technology cost estimates from the CAFE Model to the changes in sales for new vehicles in the New Vehicle Market Model, which estimates the sales impacts of alternative CAFE standards relative to the augural standards. Based on the projected changes in sales estimated in the New Vehicle Market Model and the technology costs as estimated in the CAFE Model, we estimate the technology cost savings for each of the less-stringent CAFE alternatives compared to the augural standards.

2. Results

Table 33 summarizes our estimates of the reductions in technology costs under the three alternative CAFE standards. Values for each of the alternative CAFE standards are relative to the augural standards baseline.

Table 33. Technology Costs Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Technology Costs	-$68.8	-$51.8	-$113.9	-$85.4	-$170.7	-$128.5

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.

Source: NERA/Trinity calculations as explained in text.

B. Congestion Costs

This section reports estimates of the changes in congestion costs due to the three alternative CAFE standards. Congestion cost increases arise from increases in VMT, with dollar values based on delay costs that are imposed on other drivers (thus creating an external effect). We first discuss our methodology, which is based on the methodology developed by NHTSA/EPA as described in the PRIA. We then present estimates of the congestion costs for the three alternatives relative to the augural standards baseline based on the results of our fleet population and VMT modeling.

1. Methodology

To assess the external congestion costs, we rely on estimates of congestion costs in dollars per mile ($/mile) for passenger cars and light trucks developed by the U.S. Federal Highway Administration (FHWA).[13] This parameter from FHWA represents the marginal congestion cost resulting from a unit increase in VMT. The marginal congestion cost estimates are intended to capture the costs due to added delays to other motorists associated with an additional mile traveled. FHWA has developed separate estimates for different vehicle types and for "rural" vs "urban" highway types. For a representative national value, our analysis relies on the estimates

[13] Federal Highway Administration, 1997 Highway Cost Allocation Study, Chapter V, Tables V-22 and V-23. These values were updated to 2016 dollars using the change in the Implicit Price Deflator for U.S. Gross Domestic Product, reported in U.S. Bureau of Economic Analysis, National Income and Product Accounts, Table 1.1.9.

developed by FHWA for the "Automobiles" and "Pickup and Vans" categories for the "All Highways" type.

These congestion values are summarized in Table 34. Note that these are the same values relied on by NHTSA/EPA in the PRIA.

Table 34. Marginal External Costs of Congestion (2016$/mile)

	Passenger Car	Light Truck
External Cost of Congestion	$0.0608	$0.0543

Note: Values in 2016$.
Source: Values originally developed by FHWA (1997) as cited in NHTSA/EPA (2018b).

We develop estimates of the additional external congestion costs of the three alternative CAFE standards by multiplying the values in Table 34 by the estimates of changes in VMT by vehicle type (i.e., passenger car and light truck) based upon our fleet population and VMT modeling.

2. Results

Table 35 summarizes our estimates of congestion costs for the alternative standards relative to the augural standards baseline. As shown in Table 35, the congestion costs are lower for each of the alternative standards relative to the augural standards baseline. This result is consistent with the VMT results reported in Figure 6, which show estimates of decreases in VMT due to the alternative standards. The VMT results reflect the change in the fleet age distribution (due to the scrappage effect) as well as the rebound effect.

Table 35. Congestion Costs Relative Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Congestion Costs	-$6.3	-$3.9	-$10.6	-$6.5	-$17.9	-$10.9

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.
Source: NERA/Trinity calculations as explained in text

C. Noise Costs

In this section, we develop estimates of the external costs due to noise associated with the three alternative standards. We first include a discussion of our methodology, which we develop based on NHTSA's methodology as described in the PRIA. We then present results for estimates of the noise impacts based on the results of our fleet population and VMT modeling.

1. Methodology

To assess the external noise costs, we rely on estimates of noise costs in dollars per mile ($/mile) developed by the FHWA.[14] These parameters were developed using the FHWA noise model, which estimates the loss in residential property value associated with exposure to increased noise levels. FHWA has developed separate estimates for different vehicle types and for "rural" vs "urban" highway types. For representative national values, our analysis relies on the estimates developed by FHWA for the "Automobiles" and "Pickup and Vans" categories for the "All Highways" type.

Note that the values reported for automobiles and pickups/vans is the same, so we use a single value for all vehicles in our evaluation. The value we use is shown in Table 36. This is the same valuation parameter relied on by NHTSA/EPA in the PRIA.

Table 36. Marginal External Costs of Noise (2016$/mile)

	Passenger Car	Light Truck
External Cost of Noise	$0.0008	$0.0008

Note: Values in 2016$.
Source: Values originally developed by FHWA (1997) as cited in NHTSA/EPA (2018b).

We develop estimates of the external noise costs due to the alternative standards by multiplying the values summarizes in Table 36 by the estimates of VMT we obtain from our fleet population and VMT modeling.

2. Results

Table 37 summarizes our estimates of changes in noise costs for the alternative CAFE standards relative to the augural standards baseline. As shown in Table 37, the noise costs are lower for each of the alternative standards relative to the augural standards baseline. This result is consistent with the VMT results reported in Figure 6, which show estimates of decreases in VMT due to the alternative standards. The VMT results reflect the change in the fleet age distribution (due to the scrappage effect) as well as the rebound effect.

Table 37. Noise Costs Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Noise Costs	-$0.1	-$0.1	-$0.2	-$0.1	-$0.3	-$0.2

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.
Source: NERA/Trinity calculations as explained in text

[14] Federal Highway Administration, 1997 Highway Cost Allocation Study, Chapter V, Tables V-22 and V-23. These values were updated to 2016 dollars using the change in the Implicit Price Deflator for U.S. Gross Domestic Product, reported in U.S. Bureau of Economic Analysis, National Income and Product Accounts, Table 1.1.9.

D. Crash Costs

This section provides estimates of the changes in crash costs due to the three alternative CAFE standards. We first include a brief discussion of our methodology, which we develop based on the methodology described in the PRIA. We then present results for estimates of the crash impacts based on the results of our fleet population modeling and VMT modeling. For additional information related to our methodology for estimating crash costs, please refer to Appendix I.

1. Methodology

We develop estimates of the crash costs due to the alternative standards based on the methodology used in the PRIA. This methodology includes three effects of CAFE standards on crash costs, the following two of which we use: (a) VMT effects, with more miles increasing the likelihood of a crash; (b) age distribution effects, with a greater proportion of newer vehicles decreasing the chance of a crash based upon improvements over time in safety features. The PRIA includes a third effect related to changes in the curb weight of vehicles in the fleet that is based on analysis of the link between vehicle curb weights and fatality risks. None of the estimates of that link were statistically significant in the PRIA analysis. Because of the lack of statistical significance of this effect and the conclusion in the PRIA that the effect of curb weight effects are small relative to the other two effects on crash costs,[15] we do not include effects of vehicle mass in our estimation of changes in crash costs.

We estimate fatal crash costs for non-rebound miles using the same modeling framework used in the PRIA. As in the PRIA, we then estimate non-fatal crash costs using a scalar that measures the average relationship between total fatal and total non-fatal crash costs. For details on the methodology we use to estimate crash costs, see Appendix I.

Note that we do not include crash costs associated with rebound miles in our social cost estimates, following the assumption in the PRIA that drivers internalize the safety risks of those additional miles and receive an offsetting private benefit of equal magnitude. Appendix I summarizes the explanation for this assumption in the PRIA and discusses considerations that this assumption might lead to understating changes in social costs related to vehicle crashes.

2. Results

Table 38 summarizes our estimates of changes in crash costs for the alternative standards relative to the augural standards baseline, including fatal and non-fatal crash costs. As shown in Table 38, the crash costs are lower for each of the alternative standards relative to the augural standards baseline. The reduction in crash costs is greatest for Scenario 5 and smallest for Scenario 1. This pattern reflects empirical estimates of the two competing effects of the less stringent standards on crash costs. On the one hand, the less-stringent standards lead to a newer fleet (more new vehicles and fewer existing vehicles) that has a higher average level of safety features. On the other hand, the less stringent standards result in more non-rebound VMT (as newer vehicles are driven more miles). Under Alternative 1, the higher non-rebound VMT more closely offsets the

[15] Table 11-24 on p. 1414 of PRIA.

safety benefits of newer vehicles than under Alternatives 5 and 8, resulting in a smaller difference in crash costs relative to the augural standards than the other two alternatives.

Table 38. Crash Costs Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Fatal Crash Costs	-$1.1	-$0.9	-$1.3	-$1.1	-$1.0	-$1.0
Non-Fatal Crash Costs	-$1.5	-$1.2	-$1.7	-$1.4	-$1.3	-$1.3
Total	**-$2.6**	**-$2.1**	**-$3.0**	**-$2.5**	**-$2.3**	**-$2.3**

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.

Source: NERA/Trinity calculations as explained in text.

E. Summary of Social Costs

Table 39 shows the estimated social costs of the three CAFE alternatives using 3 percent and 7 percent discount rates. The values include effects for model year vehicles up to MY 2029 based on results in calendar years from 2017 to 2050. Because the baseline ("no action" alternative) is the most stringent set of standards (augural standards), as noted above, the values for social costs for the three less-stringent CAFE standards evaluated are all negative, i.e., the values show the cost savings from the three less-stringent CAFE standards.

Table 39. Social Costs Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
Social Cost Category	**3%**	**7%**	**3%**	**7%**	**3%**	**7%**
Technology Costs	-$68.8	-$51.8	-$113.9	-$85.4	-$170.7	-$128.5
Congestion Costs	-$6.3	-$3.9	-$10.6	-$6.5	-$17.9	-$10.9
Noise Costs	-$0.1	-$0.1	-$0.2	-$0.1	-$0.3	-$0.2
Fatal Crash Costs	-$1.1	-$0.9	-$1.3	-$1.1	-$1.0	-$1.0
Non-Fatal Crash Costs	-$1.5	-$1.2	-$1.7	-$1.4	-$1.3	-$1.3
Total	**-$77.7**	**-$57.8**	**-$127.7**	**-$94.5**	**-$191.2**	**-$141.8**

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. Values may not sum to totals due to rounding.

Source: NERA/Trinity calculations as explained in text.

V. Social Benefits of Alternative CAFE Standards

This chapter provides estimates of the social benefits of the alternative CAFE standards. We include the following five social benefit categories.

1. *Fuel economy benefits*. Improvements in fuel economy reduce the cost of travel, leading to lower fuel expenditures, increased travel, and less time spent refueling. We use the New Vehicle Market Model's estimate of consumers' willingness to pay for a reduction in cost per mile to calculate the dollar value to consumers of the CAFE Model's estimated changes in vehicles' fuel economies. These estimates are supplemented by estimates of the value of changes in VMT and the value of differences in time spent refueling.

2. *Fuel tax revenue benefits*. Changes in fuel expenditures lead to changes in tax revenue collected from motor fuel sales. Note that fuel tax payments are part of consumer fuel expenditures, which are a component of consumers' valuation of fuel economy changes.

3. *Petroleum market externality benefits*. Changes in gasoline demand would lead to changes in the domestic and global petroleum markets, which could have an external effect beyond the effects experienced by new vehicle purchasers.

4. *Greenhouse gas emissions benefits*. Changes in VMT and (to a lesser extent) changes in the vehicle fleet affect GHG tailpipe emissions, and changes in fuel use lead to changes in upstream GHG emissions.

5. *Criteria pollutant emissions benefits*. Changes in the vehicle fleet and VMT lead to changes in tailpipe emissions of criteria pollutants, and changes in fuel use lead to changes in upstream emissions. We develop dollar values of these changes for emissions of nitrogen oxides (NOx), volatile organic compounds (VOC), particulate matter ($PM_{2.5}$), and sulfur dioxide (SO_2).[16]

Results are presented using both 3 percent and 7 percent discount rates. All values are present values over the period from 2017 to 2050 as of January 1, 2017, based upon information for model years up to MY 2029.

A. Fuel Economy Benefits

This section provides estimates of changes in the benefits to consumers of the fuel economy changes due to the three CAFE standard alternatives. Vehicles with greater fuel economy provide value to consumers. Most directly, the improved fuel efficiency translates into fuel savings for consumers for a given distance of travel. The decreased fuel costs also result in consumers driving more miles due to the rebound effect, however, which partially offsets those fuel savings but provides additional consumers surplus through increased mobility. Finally,

[16] Values for CO emissions are not available from the sources we relied upon for dollar-per-ton values. We note that impacts of CO emissions are highly-site specific because of little atmospheric distribution (e.g., primarily affect concentrations near roadways).

greater driving range of more fuel-efficient vehicles leads to less time spent refueling, providing consumers time savings as well.

1. Methodology

We develop estimates for the three ways in which changes in fuel economy can result in changes in consumer benefits.

a. Valuation of Fuel Economy Changes to New Vehicle Purchasers

The first component of our estimate of consumers' benefit of fuel economy improvements is the consumers' own valuation of expected fuel savings. The CAFE Model provides estimates of the changes in fuel efficiency that vehicles will achieve towards compliance in each CAFE standard alternative. We estimate consumers' willingness-to-pay for a unit decrease in fuel costs per mile in the New Vehicle Market Model based on observed market shares, vehicle attributes, and vehicle prices between 2013 and 2017 (for more details on the New Vehicle Market Model, see Appendix B). We combine this valuation from the New Vehicle Market Model with the CAFE Model results on changes in fuel economy to develop dollar values of the changes in benefits to consumers of the fuel economy changes under the three CAFE standard alternatives.

b. Valuation of Changes in VMT

We also estimate the changes in consumer surplus from the changes in mobility due to differences in fuel economy. As noted above, based on the rebound effect, consumers would change the miles they drive based upon changes in the cost-per-mile of travel. From a baseline level of miles, the decrease in cost-per-mile causes drivers to increase VMT until the marginal benefit of an additional mile decreases sufficiently to once again equal the marginal cost of the next mile. Over this range of "rebound miles," consumers would gain because the cost of those miles is less than the value of those additional miles.

c. Valuation of Changes in Driving Range

Finally, changes in the fuel efficiency of vehicles will affect the driving range for a given quantity of fuel (assuming the size of gas tanks does not change). We follow the NHTSA/EPA PRIA formulation for estimating changes in the benefits of reduced refueling time, based on assumptions about the frequency of refueling, the time spent each refuel, and the value of that time.

2. Results

Table 40 summarizes our estimates of changes in the fuel economy benefits owing to the alternative standards. Values for each of the alternative standards are relative to the augural standards baseline. Because the CAFE alternatives result in decreases in fuel economy, the results all show decreases in benefits related to fuel economy for vehicles subject to the alternative CAFE standards.

Table 40. Fuel Economy Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Valuation of Fuel Cost Savings	-$16.7	-$12.4	-$28.9	-$21.3	-$51.3	-$38.0
Rebound Mobility Benefit	-$9.7	-$5.8	-$17.4	-$10.3	-$31.0	-$18.5
Refueling Time Benefit	-$1.6	-$0.9	-$2.7	-$1.6	-$4.9	-$2.9
Benefits of Fuel Economy Changes	**-$28.0**	**-$19.1**	**-$49.0**	**-$33.3**	**-$87.2**	**-$59.5**

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.

Source: NERA/Trinity calculations as explained in text.

B. Fuel Tax Revenue Benefits

Our methodology for estimating the benefit consumers receive from the improved fuel efficiency includes changes in consumers' valuation of prospective fuel savings from improvements. Since those prospective fuel savings include foregone fuel tax payments, however, it is important to estimate the counter-acting change in fuel tax revenues. This section describes our methodology for estimating the change in fuel tax revenue and presents estimates of the differences in revenue collections for the CAFE alternatives compared to the augural standards.

1. Methodology

The fuel taxes collected in each scenario are computed by calculating motor fuel consumption in each scenario based on VMT by fuel type and applying the appropriate tax rates. We apply the same fuel taxes used in the NHTSA/EPA PRIA analysis, which include federal, state, and local tax rates.

2. Results

Table 41 summarizes our estimates of changes in the fuel tax revenue benefits due the alternative standards. Values for each of the alternative standards are relative to the augural standards baseline. Because fuel consumption is estimated to be greater under the alternative CAFE standards, the fuel tax revenues would be greater under the three alternatives than under the augural standards.

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Table 41. Fuel Tax Revenue Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Fuel Tax Revenue Benefits	$4.3	$2.6	$7.4	$4.4	$13.2	$8.0

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.

Source: NERA/Trinity calculations as explained in text.

C. Petroleum Market Externality Benefits

Changes in the demand for gasoline can lead to market externalities associated with an oil security premium. Indeed, concerns for the oil price shocks and supply disruptions in the 1970s were major factors leading to efforts to reduce U.S. petroleum demand and dependence on oil imports. In this section, we evaluate various potential sources of externalities related to U.S. petroleum demand and provide recent estimates of the likely "oil security premium" based upon the existing literature. We present results for estimates of the petroleum market externalities based upon estimates of the "oil security premium" and estimated changes in domestic and imported oil under the three CAFE alternatives. Appendix J provides more detailed information related to our methodology and results for the potential petroleum market and energy security externalities, including a sensitivity that considers alternative estimates of the oil security premium.

1. Methodology

Drawing on the discussion provided by NHTSA/EPA in the PRIA, we evaluate the impact of the alternative standards on petroleum market externality benefits through consideration of three potential factors:

1. U.S. petroleum demand and its effect on global prices;
2. Macroeconomic costs of U.S. petroleum consumption (i.e., effect of price shocks); and
3. Potential effects of fuel consumption and petroleum imports on U.S. military spending.

Consistent with the conclusion in the PRIA as well as in the recent literature as summarized in Brown (2018), we develop estimates of petroleum market externalities based only on the second of these three potential factors. The basis for this conclusion is discussed in Appendix J.

We develop monetary estimates for this category by multiplying estimates of changes in domestic and imported crude oil demand due to the alternative standards—which are based on our estimates of change in fuel consumption as summarized in Figure 6—by estimates of oil security premiums developed by Brown (2018). Brown (2018) provides separate estimates of the petroleum externality cost due to changes in imported and domestic oil consumption. These values are provided in Table 42 below for the full group of studies used by Brown (2018), which include both "older" and "newer" studies. We rely on the NHTSA/EPA PRIA assumptions for the relative shares of domestic and imported crude oil. Appendix J includes sensitivity results using the NHTSA/EPA PRIA values for oil security premiums (from the CAFE Model

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documentation and analysis files) as well as alternatives based upon use of both the "newer" and the "older" studies to show the effects of more recent estimates.

Table 42. Changes in Expected Cost of Petroleum Price Shocks from Increased Fuel Consumption (2016$/barrel)

	Consumption of Imported Oil	Consumption of Domestic Oil
Petroleum Price Shock Externality	$4.88	$3.74

Note: Values in 2016 dollars per barrel. Dollar year conversions based on implicit GDP deflator information from BEA.
Source: "PVL-C" values from Table 9 from Brown (2018).

2. Results

Table 43 summarizes our estimates of the reductions in petroleum market external benefits due the alternative standards. Values for each of the alternative standards are relative to the augural standards baseline.

Table 43. Petroleum Market Externality Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Petroleum Market Externality Benefits	-$1.3	-$0.8	-$2.2	-$1.3	-$3.9	-$2.3

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.
Source: NERA/Trinity calculations as explained in text.

D. Greenhouse Gas Emission Benefits

This section provides information on the potential changes in GHG reduction benefits due to the alternative CAFE standards. We first include a brief discussion of our methodology for developing dollar values—which are referred to as the Social Cost of Carbon (SCC)—that is based on NHTSA's methodology as described in the PRIA, which in turn is based upon an earlier EPA study. We then present results for estimates of the GHG emissions reduction benefits based on the results of our emissions modeling. For detailed information related to our methodology for valuing changes in GHG emissions please refer to Appendix K. Note that Appendix K also provides results for sensitivity cases that uses alternative estimates of the SCC.[17]

1. Methodology

We develop estimates of the GHG reduction benefits by applying estimates of the SCC—as estimated by EPA in 2017 as part of its assessment of the Clean Power Plan (CPP)—to our estimates of changes in GHG emissions. The SCC values we use in the main analysis are those

[17] See NERA (2018) for information on alternative estimates of the social costs of carbon and effects on the PRIA net benefit estimates.

included in the PRIA, which are based upon the domestic values reported in the CPP RIA for both 3% and 7% discount rates. These values are provided in Table 44 below. NHTSA/EPA note in the PRIA that they include domestic values only based on guidance from OMB Circular A-4 that the scope of the analysis "should focus on benefits and costs that accrue to citizens and residents of the United States.[18] The derivation of these SCC values is explained in Appendix K, which also includes SCC estimates based upon the global values estimated by EPA in the CPP RIA (2017).

Table 44. Social Costs of Carbon Values (2016$/metric ton)

	Discount Rate	
Year	**3.0%**	**7.0%**
2015	$6	$1
2020	$7	$1
2025	$7	$1
2030	$8	$1
2035	$9	$2
2040	$9	$2
2045	$10	$2
2050	$11	$2

Note: Values rounded to nearest whole dollar. For ease of exposition table includes annual values at five-year increments. Note that the actual analysis relies on annual-specific values for all relevant years as provided in the CAFE Model parameters file available on the NHTSA website.

Source: Table 8-24 from NHTSA/EPA PRIA (2018b); CAFE Model analysis parameters file available on the NHTSA website.

We develop estimates of changes in the GHG reductions benefits due to the three alternative CAFE standards by multiplying the SCC values in Table 44 by the GHG emissions estimates, expressed as CO_2 equivalents.

2. Results

Table 45 summarizes our estimates of the changes in GHG damage reductions benefits due the alternative standards. Values for each of the alternative standards are relative to the augural standards baseline. Appendix K provides the results of a sensitivity case in which SCC values are based on EPA's estimates of global rather than domestic impacts.

Table 45. CO_2 Reduction Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	**7%**	**3%**	**7%**	**3%**	**7%**
GHG Damage Reduction Benefits	-$1.6	-$0.2	-$2.9	-$0.3	-$7.1	-$0.7

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. GHG damage reduction benefits values include benefits associated CO_2, as well as other GHG pollutants, which have been converted to CO_{2eq}.

Source: NERA/Trinity calculations as explained in text.

[18] P. 15 of OMB Circular A-4 as cited by NHTSA/EPA (2018b) on p. 1068 of the PRIA.

E. Criteria Pollutant Emissions Benefits

This section considers the dollar values of benefits for changes in emissions of four criteria pollutants: NO_X, VOC, $PM_{2.5}$, and SO_2. We first provide a brief discussion of the information we relied upon for dollar benefit-per-ton values for emissions for tailpipe and upstream emissions. We then present estimated dollar values for the changes in criteria pollutant emissions based on the results of our emissions modeling. For detailed information on the information used to value changes in criteria emissions, see Appendix L.

1. Methodology

To value changes in criteria pollutant emissions we rely primarily on a recent EPA study of the dollar benefits-per-ton of reduced emissions (EPA 2018).[19] Estimates of criteria pollutant benefits are based upon multiplying the estimates of changes in pollutant tons by the national dollar-per-ton values. EPA (2018) reports dollar values based on air emissions modeling, population exposure modeling, dose-response functions for various health effects, and dollar values of these various health effects that are developed in a 2017 version of its environmental Benefits Mapping and Analysis Program—Community Edition (BenMAP-CE). EPA (2018) provides dollar-per-ton values for NO_X, SO_2, and $PM_{2.5}$. For VOC, we rely upon the dollar-per-ton value developed by NHTSA in the PRIA. Appendix L includes a description and summary tables of the benefits-per-ton values used in our calculations, along with a summary of the uncertainties and limitations that EPA identifies related to the development of these estimates and their application to specific regulations.

2. Results

Table 46 summarizes our estimates of the criteria pollutant damage reductions benefits due the alternative standards. Results for each of the alternative CAFE standards are relative to the augural standards baseline.

Table 46. Criteria Pollutant Emissions Reductions Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
NO_x Damage Reduction Benefits	$0.0	$0.0	$0.1	$0.1	$0.0	$0.0
VOC Damage Reduction Benefits	$0.0	$0.0	-$0.1	$0.0	-$0.1	-$0.1
$PM_{2.5}$ Damage Reduction Benefits	-$0.4	-$0.2	-$0.8	-$0.5	-$1.7	-$1.0
SO_2 Damage Reduction Benefits	-$2.0	-$1.2	-$3.4	-$2.0	-$6.1	-$3.6
Total	**-$2.4**	**-$1.4**	**-$4.2**	**-$2.5**	**-$8.0**	**-$4.7**

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. Values may not sum to totals due to rounding.
Source: NERA/Trinity calculations as explained in text.

[19] U.S. Environmental Protection Agency (EPA), 2018. "Technical Support Document Estimating the Benefit per Ton of Reducing $PM_{2.5}$ Precursors from 17 Sectors." February.

F. Summary of Social Benefits

Table 47 shows the social benefits of the three CAFE alternatives using 3 percent and 7 percent discount rates. The values include effects for model year vehicles up to MY 2029 based on impacts in calendar years from 2017 to 2050. Because the baseline ("no action" alternative) is the most stringent set of standards (augural standards), the values for social benefits for the three less-stringent CAFE standards are mostly negative, i.e., the values show the reductions in benefits from less-stringent standards. The exceptions are government fuel tax revenue (which is greater due to the larger fuel use from the less stringent CAFE standards) and some criteria pollutants (which have greater benefits because reductions in tailpipe emissions are larger than increases in upstream emissions).

Table 47. Social Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
Social Benefits Category	**3%**	**7%**	**3%**	**7%**	**3%**	**7%**
Valuation of Fuel Economy Benefits	-$28.0	-$19.1	-$49.0	-$33.3	-$87.2	-$59.5
Fuel Tax Revenue Benefits	$4.3	$2.6	$7.4	$4.4	$13.2	$8.0
Petroleum Market Externality Benefits	-$1.3	-$0.8	-$2.2	-$1.3	-$3.9	-$2.3
GHG Damage Reduction Benefits	-$1.6	-$0.2	-$2.9	-$0.3	-$7.1	-$0.7
NO_x Damage Reduction Benefits	$0.0	$0.0	$0.1	$0.1	$0.0	$0.0
VOC Damage Reduction Benefits	$0.0	$0.0	-$0.1	$0.0	-$0.1	-$0.1
$PM_{2.5}$ Damage Reduction Benefits	-$0.4	-$0.2	-$0.8	-$0.5	-$1.7	-$1.0
SO_2 Damage Reduction Benefits	-$2.0	-$1.2	-$3.4	-$2.0	-$6.1	-$3.6
Total Social Benefits	**-$29.0**	**-$18.9**	**-$50.9**	**-$32.9**	**-$93.0**	**-$59.3**

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. GHG damage reduction benefits values include benefits associated CO_2, as well as other GHG pollutants, which have been converted to CO_{2eq}. Values may not sum to totals due to rounding.

Source: NERA/Trinity calculations as explained in text.

VI. Net Benefits of Alternative CAFE Standards

This chapter provides information on the net benefits of the three alternative CAFE standards, i.e., benefits minus costs.

A. Net Benefits Using a 3 Percent Discount Rate

Table 48 summarizes the total social benefits, total social costs, and net benefits associated with each of the alternatives considered using a 3 percent discount rate.

Table 48. Net Benefits Relative to Augural Standards Baseline, 3% Discount Rate (billions of 2016$)

	Scenario 8	Scenario 5	Scenario 1
Social Costs			
Technology Costs	-68.8	-113.9	-170.7
Congestion Costs	-6.3	-10.6	-17.9
Noise Costs	-0.1	-0.2	-0.3
Fatal Crash Costs	-1.1	-1.3	-1.0
Non-Fatal Crash Costs	-1.5	-1.7	-1.3
Total Social Costs	**-77.7**	**-127.7**	**-191.2**
Social Benefits			
Valuation of Fuel Economy Benefits	-28.0	-49.0	-87.2
Fuel Tax Revenue Benefits	4.3	7.4	13.2
Petroleum Market Externality Benefits	-1.3	-2.2	-3.9
GHG Damage Reduction Benefits	-1.6	-2.9	-7.1
NO_x Damage Reduction Benefits	0.0	0.1	0.0
VOC Damage Reduction Benefits	0.0	-0.1	-0.1
$PM_{2.5}$ Damage Reduction Benefits	-0.4	-0.8	-1.7
SO_2 Damage Reduction Benefits	-2.0	-3.4	-6.1
Total Social Benefits	**-29.0**	**-50.9**	**-93.0**
Net Total Benefits	**48.7**	**76.8**	**98.2**

Note: Present values calculated as of January 1, 2017 using a 3 percent discount rate for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. GHG damage reduction benefits values include benefits associated CO_2, as well as other GHG pollutants, which have been converted to CO_{2eq}. Values may not sum to totals due to rounding.

Source: NERA/Trinity calculations as explained in text.

B. Net Benefits Using a 7 Percent Discount Rate

Table 49 provides estimates of the changes in social costs, changes in social benefits, and the net benefits using a 7 percent discount rate.

Table 49. Net Benefits Relative to Augural Standards Baseline, 7% Discount Rate (billions of 2016$)

	Scenario 8	Scenario 5	Scenario 1
Social Costs			
Technology Costs	-51.8	-85.4	-128.5
Congestion Costs	-3.9	-6.5	-10.9
Noise Costs	-0.1	-0.1	-0.2
Fatal Crash Costs	-0.9	-1.1	-1.0
Non-Fatal Crash Costs	-1.2	-1.4	-1.3
Total Social Costs	**-57.8**	**-94.5**	**-141.8**
Social Benefits			
Valuation of Fuel Economy Benefits	-19.1	-33.3	-59.5
Fuel Tax Revenue Benefits	2.6	4.4	8.0
Petroleum Market Externality Benefits	-0.8	-1.3	-2.3
GHG Damage Reduction Benefits	-0.2	-0.3	-0.7
NO_x Damage Reduction Benefits	0.0	0.1	0.0
VOC Damage Reduction Benefits	0.0	0.0	-0.1
$PM_{2.5}$ Damage Reduction Benefits	-0.2	-0.5	-1.0
SO_2 Damage Reduction Benefits	-1.2	-2.0	-3.6
Total Social Benefits	**-18.9**	**-32.9**	**-59.3**
Net Total Benefits	**38.9**	**61.6**	**82.6**

Note: Present values calculated as of January 1, 2017 using a 7 percent discount rate for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. GHG damage reduction benefits values include benefits associated CO_2, as well as other GHG pollutants, which have been converted to CO_{2eq}. Values may not sum to totals due to rounding.
Source: NERA/Trinity calculations as explained in text.

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Appendix A: CAFE Model and Application to This Project

This appendix provides an overview of the CAFE Model and describes its implementation by Trinity Consultants (Trinity). The CAFE Model discussed in this appendix refers to the July 2018 version developed by National Highway Traffic Safety Administration (NHTSA) to support the proposed Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Year 2021-2026 Passenger Cars and Light Trucks. Trinity similarly applied the 2018 CAFE Model (subsequently referred to as the CAFE Model) to estimate changes in vehicle, manufacturer and fleet compliance costs, technology penetrations and fuel economy levels needed to meet various alternative CAFE standards. A brief overview of the design/layout of the CAFE Model is presented first, followed by a discussion of the specific implementation of the CAFE Model for the analyses prepared in this study.

A. Overview of CAFE Model

The CAFE Model is designed to evaluate how vehicle manufacturers would comply with a given set of user-specified alternative fuel economy standards. From that evaluation, the model estimates penetrations of various technologies and the additional compliance costs for each manufacturer over each future model year. The baseline model (MY) year is MY 2016, and the CAFE Model evaluates compliance through MY 2032. In addition to compliance costs and technology penetrations, the CAFE Model also estimates changes in fuel consumption, vehicle emissions and various other social costs and benefits due to different CAFE alternatives. As noted in the body of this report, different models were used by NERA Economic Consulting (NERA) and Trinity to develop estimates of these other effects of CAFE alternatives, and thus we do not discuss these other aspects of the CAFE Model in this appendix.

Manufacturer compliance simulation within the CAFE Model starts with a user-specified vehicle model-level baseline fleet (with initial vehicle attributes and projected sales). The model then evaluates an array of possible compliance paths that incorporate additional vehicle technologies (beyond those within the baseline fleet) which provide various levels of fuel economy improvement. For each manufacturer fleet, the model evaluates plausible combinations of technology applications (i.e., the technology paths), seeking that path with the best cost-effectiveness, subject to several user-selected factors such as individual manufacturer willingness to pay, CAFE undercompliance penalties, and accumulation/carry forward of overcompliance credits from preceding model years.

Although the cost and effectiveness of each technology can be set by the user, we emphasize the Trinity made no changes to these inputs and used the reference values developed by NHTSA that were loaded into the CAFE Modeling system.

Once the CAFE Model has identified the optimal compliance path for each manufacturer (weighing difference technology combinations on different vehicles within the manufacturers passenger car and light truck fleets), it produces output reports on vehicle and manufacturer averaged technology application and costs.

Key elements of the CAFE Model's input files, user-selectable runtime configuration options, and output reports are summarized below.

1. Input Files

Inputs to the CAFE Model are organized into four user-configurable spreadsheet files summarized as follows:

1. *Market Data File*. This file contains detailed vehicle-level attribute data (size, footprint, baseline fuel economy and technology and model year sales) within a "Vehicles" worksheet. Detailed information on engine and transmission attributes and technology applicability is also defined in separate "Engines" and "Transmissions" worksheets, respectively. Finally, the "Manufacturers" worksheet specifies manufacturer-specific inputs that are germane to the compliance simulation such as individual manufacturer willingness to pay fines and baseline CAFE credit balances.
2. *Technologies File*. These estimates of the costs and availability of individual technologies are defined in this file. The CAFE Model evaluates compliance using a total of 66 individual vehicle, engine and transmission technologies. Cost information includes vehicle/engine size specific technology costs by model year as well as advanced hybrid/electric battery learned cost factors and stranded capital costs (where applicable). Cost synergies to address applicable engine technology combinations are also defined in this file.
3. *Parameters File*. These inputs are used to calculate various parameters used in the model are included in this file. The inputs include those used to develop information on the manufacturers' compliance plans as well as others that are used in subsequent calculations of social costs and social benefits.
4. *Scenarios File*. Fuel economy and CO_2 standards scenarios defining the coverage, structure and year-to-year stringency are specified in the Scenarios file. Note that in keeping with the main report, we describe different standards as alternative CAFE standards rather than scenarios.

2. Runtime Settings

Various run configuration options can be enabled/disabled or specified within the CAFE Model's "Runtime Settings" panel within the user interface. The ones relevant for our analyses are summarized below[20]:

- *Compliance Program to Enforce*. This specifies the compliance program the model should enforce when evaluating a manufacturer's compliance state. If "CAFE" option is

[20] "Draft CAFE Model Documentation," U.S. Department of Transportation, National Highway Traffic Safety Administration, July 2018, ftp://ftp.nhtsa.dot.gov/CAFE/2021-2026_CAFE_NPRM/CAFE_Model/CAFE_Model/CAFE_Model_Documentation_NPRM_2018.pdf

selected, the model will seek compliance with NHTSA's CAFE standards. If "CO-2" option is selected, the system will seek compliance with EPA's CO_2 standards.

- *Fuel Price Estimates*. This specifies whether to use the low, average, or high fuel price estimates from the parameters input file. By default, average fuel price estimates are used.

- *Begin Technology Application Starting In*. This specifies the starting model year when the system will begin evaluating technologies for application on vehicles. Prior to this year, the system will only determine manufacturers' compliance levels, generate available credits and fines owed, and use expiring credits (if credit trading option is enabled) to offset compliance shortfalls as needed. Any non-expiring banked credits available prior to start of the analysis (which are specified as input for each manufacturer) will not be used for model years prior to this starting year.

- *Allow Credit Trading*. This specifies whether the model should allow manufacturers to transfer credits between passenger car and light truck fleets and to carry-forward credits forward from previous model years into the analysis year. (The model currently does not simulate either credit "carry-back" or trading between different manufacturers.)

- *Last Credit Trading Year*. This specifies the last model year during which credits may be transferred or carried forward. A value of 2020 indicates that manufacturers may transfer and carry forward credits through and including model year 2020.

- *Perform Fleet Analysis Calculations*. This specifies whether the model should perform fleet analysis calculations, evaluating modeling effects for historic and forecast model years (before the first compliance model year as well as after the last compliance model year).

3. Output Results

Finally, the CAFE Model's outputs include a series of "report" files in CSV format. The following are the reports relevant for our study.

- *Compliance Report*. This provides manufacturer-level and industry-wide summary of compliance model results for each model year and scenario analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.

- *Technology Utilization Report*. This provides manufacturer-level and industry-wide technology application and penetration rates for each technology, model year, and scenario analyzed. The results are disaggregated by regulatory class, as well as combined over the entire fleet.

- *Vehicles Report*. This provides a detailed view of the final state of each vehicle examined by the model, for each model year and CAFE alternative analyzed.

B. Trinity Implementation of CAFE Model

Trinity considered four CAFE standards—including the augural standards and three alternatives—as noted in the main report. Table A-1 summarizes these four CAFE standard alternatives.

Table A-1. CAFE Alternatives Evaluated in This Study

Alternative	Change in stringency
Baseline/ No-Action ("Augural")	MY 2021 standards remain in place; MYs 2022-2025 augural CAFE standards are finalized; MY 2026 standards are set at MY 2025 levels
8	Existing standards through MY 2021, then 2%/year increases for passenger cars and 3%/year increases for light trucks, for MYs 2022-2026
5	Existing standards through MY 2021, then 1%/year increases for passenger cars and 2%/year increases for light trucks, for MYs 2022-2026
1	Existing standards through MY 2020, then 0%/year increases for both passenger cars and light trucks, for MYs 2021-2026

Note: There are no changes in A/C Efficiency or off-cycle provisions.

1. CAFE Model Input Files and Runtime Settings

The CAFE Model input files and runtime settings were set to those used by NHTSA to support the "Unconstrained" analysis[21] referred to in the Draft Environmental Impact Analysis (DEIS). Table A-2 presents a detailed listing of the CAFE Model input files and runtime settings used in the analysis.

[21] As described in Section 2.3.2 of the DEIS, NHTSA's CAFE Model results presented in the NPRM differ slightly from those presented in the DEIS. EPCA and EISA require that the Secretary determine the maximum feasible levels of CAFE standards in a manner that sets aside the potential use of CAFE credits or application of alternative fuels toward compliance with new standards. NEPA, however, does not impose such constraints on analysis; instead, its purpose is to ensure that "public officials make decisions with an understanding of environmental consequences." The DEIS therefore presents results of an "unconstrained" analysis that considers manufacturers' potential use of CAFE credits and application of alternative fuels in order to disclose and allow consideration of the real-world environmental consequences of the Proposed Action and alternatives.

Table A-2. CAFE Model Configurations Used in This Study

Category	Primary Option	Matches NHTSA Unconstrained?
Input File Options		
Market Data (– Payback Period)	60 months	No
Market Data (Manufacturers– Fines Preference)	Defaults by manufacturer	Yes
Technologies – BEV200s and FCV availability	Used "BEV_FCV" input file	Yes
Parameters (Safety Values) – Weight-Related Fatalities	0%	Yes
Scenarios (Fine Rate)	$5.50 in MY 2016, 1% Discount Rate	Yes
Runtime Settings		
StartYear	2017	Yes
ComplianceProgram	CAFE	Yes
MultiYearModeling	True	Yes
AllowCreditTrading	True	Yes
LastCreditTradingYear	2032	Yes
NoFines	False	Yes
Backfill	True	Yes
FleetAnalysis	True	Yes
DynamicFleetShare	False	No
DynamicScrappage	False	No
ConsumerBenefitsScale	Turned off	Yes
FuelPriceEstimates	Average	Yes
CO2Estimates	Average	Yes

Note: There are no changes in A/C Efficiency or off-cycle provisions.

Apart from three settings that reflect the use of substitute results from the New Vehicle Market Model and the Scrappage Model—as discussed in Appendices B and C—the CAFE Model input files were the same as those used by NHTSA in their Unconstrained DEIS analysis. (This included use of NHTSA's "2018_NPRM_technologies_with_BEV_and_FCV_ref.xlsx" Technologies file input which enables application of alternative technologies/fuels consistent with the Unconstrained case.)

The payback period is a required setting in the CAFE Model. A value of 60-months was used for this setting in the Trinity implementation of the CAFE Model—replacing the 30-month value used in the PRIA—for consistency with the results of the New Vehicle Market Model (which provides an estimate of the value new vehicle purchasers place on fuel economy improvements).

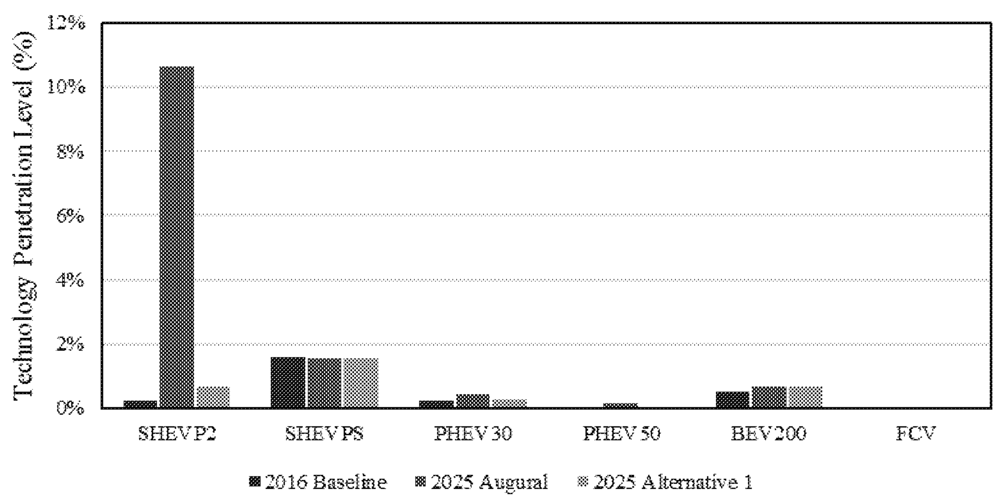
2. Advanced Powertrain Projections in CAFE Model

As noted earlier, the CAFE Model evaluates over 60 individual technologies within a series of technology pathways to identify the optimum pathway and the compliance costs and fuel economy changes associated with that pathway. These calculations are performed for each manufacturer's unique fleet. This subsection summarizes CAFE Model projections for "advanced powertrain" technologies, which refers to strong hybrids, plug-in electric hybrids, battery electric vehicles and fuel cell vehicles. This definition encompasses six individual technologies within the CAFE Model as follows:

- SHEVP2 – P2 parallel strong hybrid;
- SHEVPS – Power split strong hybrid;
- PHEV30 – Plug-in hybrid electric vehicle, 30-mile battery range;
- PHEV50 – Plug-in hybrid electric vehicle, 30-mile battery range;
- BEV200 – 200-mile battery electric vehicle; and
- FCV – fuel cell vehicle.

Figure A-1 shows the CAFE Model projected advanced powertrain technology levels in model year 2025 under both the augural standards and the Alternative 1 standards and compares these projected levels to those that currently exist in MY 2016 (the baseline year for the CAFE Model). The technology penetration levels shown in Figure A-1 are sales-weighted averages across all manufacturers' light-duty vehicle fleets.

Figure A-1. CAFE Model Advanced Powertrain Technology Penetration Levels



As shown in Figure A-1, with the exception of P2 strong hybrids (which are projected to increase from 0.23% in the 2016 baseline to 10.66% by MY 2025 under compliance with the augural standards), the CAFE Model projects little change in other advanced powertrain fleet penetration levels under either the augural standards or the Alternative 1 standards by 2025.

Under the augural standards, the CAFE Model projects nominally higher PHEV levels in 2025 than 2016 (for example, 0.46% vs. 0.24% respectively for PHEV30). The CAFE Model also projects small increases in penetration levels of pure electric vehicles (BEV200) under either alternative: 0.67% under the augural standards and 0.66% under Alternative 1 in 2025 relative to the current 2016 baseline level of 0.52%.

These modest changes in projected advanced powertrain technology levels are the result of the CAFE Model's technology path optimization logic, which seeks to calculate the most cost-effective compliance path for each manufacturer's vehicle fleets.

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Appendix B: New Vehicle Market Model

This appendix provides information on the New Vehicle Market Model, the model developed by NERA to model the market for new motor vehicles. The New Vehicle Market Model is used in this study to develop estimates of the value that consumers place on fuel economy improvements and, in conjunction with the results of the CAFE Model for compliance costs, to develop projections of new motor vehicle sales under the three CAFE alternatives.

A. Conceptual Approach: Nested Logit Model

Logit discrete choice analysis provides a method for predicting consumer choices, and therefore demand, based on previously observed consumer behavior and other assumptions about demand (see, e.g., Ben-Akiva and Lerman 1985). The most basic logit model, also referred to as the simple logit, groups all product alternatives together and therefore allows only limited variation in own-price and cross-price elasticity between different alternatives. This limitation is often referred to as the "Independence of Irrelevant Alternatives" ("IIA") property. The nested logit model builds on this simple framework, while allowing for a much richer pattern of cross-substitution between different alternatives through the nesting structure.

1. Basic Framework

In our New Vehicle Market Model, consumers choose among a set of vehicle models, and may also choose not to purchase a vehicle at all. For alternative (vehicle model) i, the utility that a given consumer obtains from choosing that alternative can be written as a function of an alternative-specific parameter and the price for the alternative:

$$\boldsymbol{U_i = \alpha_i - \beta P_i + \varepsilon_i} \qquad \textbf{(1)}$$

Alternative "0" is defined as the no-purchase alternative, and the remaining alternatives represent decisions to purchase individual vehicle models. The parameter α_i measures the attractiveness of good i to consumers. We assume that the price for the outside good is zero. P_i is the price of alternative i, and β is a positive coefficient. The random error terms ε_i are assumed to be distributed as a multivariate generalization of the standard extreme value distribution. It is this assumption about the distribution of the error terms that gives rise to the logit model.

The potential purchaser is assumed to choose the alternative that yields the highest utility, taking into account both the deterministic and random components of utility. Given the logit demand assumptions, we determine the expected market share for each vehicle model. Conditional upon the consumer's decision to purchase a vehicle model within a vehicle group (or "nest") A (as described below), the expected share for vehicle model i can be written as:

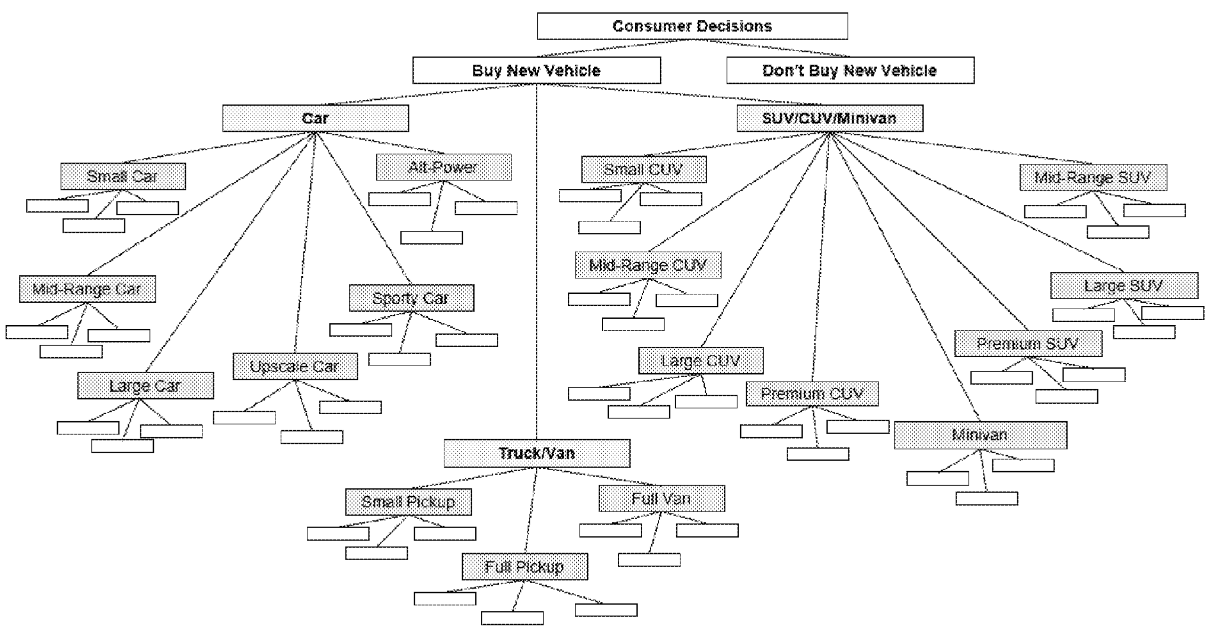
$$\boldsymbol{s_{i|A} = \frac{\exp((\alpha_i - \beta P_i)/\lambda_A)}{\sum_{j \in A} \exp((\alpha_j - \beta P_j)/\lambda_A)}} \qquad \textbf{(2)}$$

where λ_A is the "nesting parameter" for the appropriate vehicle group, or "nest" (as described below).

2. Nesting Assumptions

Our logit model assumes the nesting structure shown in Figure B-1. We divide the choice problem first into the decision of whether to buy a new vehicle. Conditional upon the choice to purchase a new vehicle, consumers choose the vehicle type—in this case, passenger cars; pickup trucks or full-size vans; and SUVs, CUVs, or minivans. Conditional on the choice of vehicle type, consumers choose the vehicle class—for example, small cars or mid-range cars (among others) in the passenger-car group. Conditional on the vehicle class (e.g., mid-range car, small SUV, etc.), consumers choose one of the individual vehicle models available. The bottom level of the nesting structure includes 296 vehicle models from which consumers may choose.

Figure B-1. Nesting Structure for New Vehicle Market Model



The new vehicle market model allows the utility that consumers derive from the purchase of different models to depend on the vehicle category and class via the nesting parameters (λ_A), which take values between zero and one[22]. One nesting parameter applies to the purchase decision (buy or do not buy a vehicle); another nesting parameter applies to the choice of vehicle type; and a third applies to the choice of vehicle classes. The nesting parameters for the purchase decision must be at least as large as the nesting parameter for all vehicle nests contained within the "parent" nest. The nesting structure implies that vehicles within one group are closer substitutes for each other than they are for vehicles in different groups. The cross-price

[22] The nesting parameters are sometimes called "inclusive value coefficients."

elasticities between vehicles within the same group are therefore higher than the cross-price elasticities for vehicles in different groups.

As noted above, one advantage of the nested logit model over the simple logit model is that it provides for a richer pattern of own- and cross-price elasticities. In the nested logit model, the IIA property need not hold across groups. That is, the ratio of the share for a particular car model in one bottom-level nest to the share of a vehicle in a different bottom-level nest, for example, depends not only on the characteristics of those two vehicle models, but also on the substitution patterns implied by the nesting structure and nesting parameters. The nesting parameters therefore enrich the simple logit model. If all nesting parameters equal one, then the nested logit model becomes a simple logit model.

The inclusive value term I_A for the bottom-level group A (the vehicle class) is defined as:

$$\boldsymbol{I_A = \ln\left[\sum_{j \in A} \exp((\alpha_j - \beta P_j)/\lambda_A)\right]} \tag{3}$$

The inclusive value term I_X for the top-level group X (the vehicle type) is defined as:

$$\boldsymbol{I_X = \ln\left[\sum_{A \in X} \exp(I_A \lambda_A)/\lambda_X)\right]} \tag{4}$$

Finally, the inclusive value term for the purchase alternative is defined as:

$$\boldsymbol{I_X = \ln\left[\sum_{X} \exp(I_X \lambda_X)/\lambda_{buy})\right]} \tag{5}$$

The share of the bottom-level group A in purchases within the top-level group X to which A belongs can be written as:

$$\boldsymbol{s_{A|X} = \frac{\exp(I_A \lambda_A)/\lambda_X)}{\sum_{B \in X} \exp(I_B \lambda_B)/\lambda_B)}} \tag{6}$$

The share of top-level group X in total purchases can be written as:

$$\boldsymbol{s_{X|buy} = \frac{\exp(I_X \lambda_X)/\lambda_X)}{\sum_{Y} \exp(I_Y \lambda_Y)/\lambda_Y)}} \tag{7}$$

The logit framework gives an expression for the share of potential buyers who choose to purchase a vehicle:

$$\boldsymbol{s_{buy} = \frac{\exp(I_{buy} \lambda_{buy})/\lambda_{buy})}{\exp\left(I_{buy} \lambda_{buy}\right) + \exp(\alpha_0)}} \tag{8}$$

where α_0 is the value derived by the consumer from a no-purchase decision.

The unconditional share for alternative i can be written as the product of the purchase probability and the conditional probabilities:

$$\boldsymbol{s_i = s_{buy} s_{X_i|buy} s_{A_i|X_i} s_{i|A_i}} \quad \textbf{(9)}$$

where A_i is the bottom-level group to which i belongs and X_i is the top-level group to which A_i belongs.

B. Solving for Parameters

As described above, the nested logit choice framework provides a method to estimate consumer demand for differentiated products, using as data the prices and parameters that measure the relative attractiveness of each product. Using the logit framework, we solve simultaneously for the beta parameters and "alternative-specific" parameters that are consistent with the observed market shares and prices. If two products in the same group have the same price but different market shares, then the one with the higher share must be more attractive to consumers. Similarly, if two products in the same group have the same market share but different prices, then the one with the higher price must be more attractive to consumers, since consumers are observed to pay a premium for it.

We use the logit framework to calibrate alternative-specific parameters for each vehicle model. We make assumptions concerning the nesting parameters, the aggregate price elasticity of demand, and the price elasticity of demand for one specific normalized alternative. Given the structure of our nested logit model, these assumptions, the observed prices, and the observed market shares are sufficient to derive estimates of the alternative-specific parameters (including those for the outside good).

C. Estimating Consumer Valuation of Vehicle Attributes

Once the alternative-specific parameters implied by the observed vehicle shares and prices are calculated, we estimate the extent to which consumers value each vehicle attribute through a "second-stage" regression for the alternative-specific parameters. We consider the effects of specific vehicle attributes such as horsepower/weight (a common measure of acceleration), size (length multiplied by width), and the cost of fuel per mile driven ($/mile, which is the product of gallons-per-mile and the fuel price).

We assume each vehicle's alternative-specific parameter depends upon the vehicle's model and attributes according to the following model:

$$\boldsymbol{\alpha = \varphi X + \delta_{year} D_{year} + \delta_{season} D_{season} + \phi_{model} D_{model} + \varepsilon} \quad \textbf{(10)}$$

where

α is the alternative-specific coefficient at time t,

X are vehicle characteristics at time t,

D_{year} are dummy variables corresponding to vehicle model years,

D_{season} are dummy variables corresponding to seasons (calendar quarters),

D_{model} are dummy variables corresponding to the vehicle model, and

ε is an error term capturing unobserved characteristics

Our model uses quarterly data on sales and prices combined with information on vehicle characteristics for each model year. Thus, the t subscript indexes quarters. We estimated this equation using ordinary least squares (OLS) and tested for the presence of autocorrelation in the error terms. We found significant autocorrelation, as evidenced by a statistically significant coefficient on the lagged residuals in a regression of the residuals from the OLS estimation on the residuals lagged one period. To correct for autocorrelation in the error terms, we re-estimated the equation using feasible generalized least-squares (FGLS) with first-order autoregressive disturbances. In this model, the error terms are related to their lagged values by a parameter ρ between 0 and 1.

Table B-1 reports the result of this regression. The coefficients on size and horsepower/weight are positive and significant, as expected. The model-year, seasonal, and vehicle-model sets of categorical dummy variables are each jointly significant. The coefficient on $/mile is negative, as expected (the higher the $/mile, the higher the operating cost, and the less a consumer would value the vehicle, controlling for other factors) and highly significant. The estimated coefficient provides a means of valuing improvements in miles per gallon (decreases in $/mile) that can be used to estimate the benefits to new vehicle purchasers of changes in fuel economy.

Table B-1. Estimation Results for Alternative-Specific Parameter Model

Independent variable	coeff.	t-statistic	std. error	p > |t|
$/mile	-2.559	-8.211	0.312	0.0000
hp/weight	2.158	3.001	0.719	0.0027
size	0.649	4.546	0.143	0.0000
constant	-2.112	-9.726	0.217	0.0000
categorical dummies	**significance test**	**$\chi 2$ -statistic**		**p > |$\chi 2$|**
Model Year	$\chi 2$	474.031		0.0000
Season	$\chi 2$	383.266		0.0000
Vehicle Model	$\chi 2$	6684.904		0.0000
Autocorrelation parameter	**estimated value**			
ρ	0.7846			
σ	0.1257			

Note: The weight variable is curb weight in units of pounds. The size variable is the product of vehicle length and width (both expressed in hundreds of inches).
Source: NERA calculations as explained in text.

The dollar value of a unit improvement in a vehicle attribute can be inferred from this model by taking the ratio of the coefficient on that attribute to the price coefficient (the β term in Equation (1)) multiplied by -1. We express price in units of $20,000. The average β parameter estimate across all quarters in the New Vehicle Market Model is 0.737. Thus, the dollar value Willingness-to-Pay (WTP) for a $0.01/mile reduction in operating costs can be calculated as:

$$WTP_{\$0.01/mile} = \frac{-2.559}{-0.737} * 200 = \$694 \tag{11}$$

That is, improving fuel economy by an amount equivalent to lowering the cost per mile by $0.01 is worth an extra $694 in the price of a new vehicle. For example, suppose the MPG of an average vehicle increases from 30 MPG to 35 MPG at a gasoline price of $2.50. At 30 MPG, vehicle fuel costs $2.50/30 = $0.0833 per mile. At 35 MPG, the cost is $2.50/35 = $0.0714 per mile, for a reduction of $0.0833 - $0.0714 = $0.0119 per mile, or 1.119 cents per mile. This reduction in fuel cost per mile should be worth about 1.119 * $694 = $777 based upon the information implied in vehicle purchasers' behavior.

D. Specific Implementation Parameters and Data

a. Vehicle Sales

We use quarterly vehicle sales data from J.D. Power and Associates to determine the market share for each vehicle model, aggregated across trim levels, for MYs 2013-2017. We match model year vehicle characteristics to sales from October of the previous calendar year to September of the same calendar year to reflect as accurately as possible the timing of new model availability. For example, vehicle characteristics for MY 2014 vehicles are paired with sales data for the fourth quarter of 2013 through the third quarter of 2014. If a vehicle model sold less than

200 units in a given quarter, we eliminated it from the data set for that quarter. We also eliminated observations where models sold substantially more or fewer units than the following or previous period to avoid biasing our estimates of attributes valuation due to the introduction or discontinuation of vehicle models.

b. Vehicle Prices

We use quarterly data on transaction prices for each model from J.D. Power and Associates for the United States. The transaction prices are sales weighted across trims and reflect the different prices charged for different trim levels.

c. Vehicle Fuel Economy Data and Other Vehicle Characteristics

We rely on vehicle characteristic data that we acquired from Ward's Automotive for each model in our sample. The data we acquired from Ward's included fuel economy information based on the fuel economy metrics maintained by EPA as reported on fueleconomy.gov. While EPA maintains several measures of fuel economy, for this analysis we use the two-cycle definition of fuel economy (i.e., EPA unadjusted) for consistency with the metric NHTSA uses to set CAFE Standards. We also rely on data from Ward's for information on other vehicle attributes, including curb or test weight, horsepower, length, and width.

Note that the Ward's dataset is organized at the trim level. We match the Ward's characteristics for the trim level with the highest sales (based on the JDPA sales data) to the JDPA sales volume and transaction price data. For certain vehicle trim levels in the Wards data, there are multiple versions within a trim (e.g., differing powertrain and transmission options). In these instances, we average across the various options within a certain trim level.

d. Categorization of Vehicle Models into Nests

We use vehicle categorizations from the 2013-2016 Automotive News Market Data Book to define the vehicle nesting structure depicted in Figure B-1. Where the appropriate category for a particular model could not be determined, including models new to 2017 for which Automotive News did not publish categorizations, we used Ward's categorizations and/or the categorization of comparable vehicles.

The Automotive News Market Data Books include hybrids and electric vehicles in an "Alt. Power" category within the cars segment of the market. Following this, we place all alternative power vehicles in an "Alt. Power" nest within the cars nest. As a sensitivity check, we explored alternative nesting strategies for these vehicles, including assigning alternative power vehicles to the same nest as their criteria power counterpart as available (e.g., the RAV4 Hybrid would be in the same nest as the RAV4) and having alternative power vehicles as an additional upper level nest. None of these alternative strategies yielded significantly different results.

e. Price Elasticity

Consistent with various literature sources, we assume an aggregate elasticity for the new vehicle market of -1.0[23]. We set the own-price elasticity of the "normalized" vehicle model (whose alternative-specific parameter is normalized to zero) to be -4.0, which is consistent with various other literature estimates of individual model own-price elasticities.[24]

The nesting parameters for nested logit models represent the similarity between choices for vehicles falling within the same "nest". The nesting parameters influence the relative substitutability within each nest, and also between different nests. Nesting parameters may take any value between zero and one, with lower values indicating greater similarity between the alternatives within the respective nest. For the "Buy" nest we use a nesting parameter equal to 0.9, for vehicle types we use a nesting parameter equal to 0.6 and for vehicle classes we use a nesting parameter equal to 0.3.

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[23] See, for example, Gruenspecht (2000).

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Appendix C: Scrappage Model

This appendix provides information on the Scrappage Model developed by NERA for use in this study.

A. Vehicle Prices and Scrappage Behavior

The idea that economic as well as technical considerations can influence the life spans of durable capital goods such as motor vehicles has long been recognized. Specifically, the link between a vehicle's market value and its service lifetime was first explicitly recognized more than three decades ago. This logic is straightforward: a vehicle is retired from service (or scrapped) when it is no longer worth the expense of keeping it in working condition. That is, when the difference between the vehicle's resale price (in working condition) and the cost of keeping it in this condition is less than its scrap value, the vehicle is scrapped.

Building on this basic insight, early research by Walker (1968) and Parks (1977) investigated the influence of a vehicle's market value, as well as characteristics such as its age, on the vehicle owner's decision to retire the vehicle from service rather than maintain it in working condition. Both authors present statistical evidence of the influence of vehicle prices on the scrappage rates of used vehicles of different model year vintages and ages, demonstrating that variation in automobile prices exerts a detectable influence on scrappage rates of used cars. Berkovec (1985) later incorporated the framework developed in this earlier research in a model encompassing new automobile production and sales activity, vehicle pricing behavior, and scrappage of used autos.

Also drawing on previous results, Gruenspecht (1982) recognized that the connection between new and used vehicle prices—whereby rising prices for new models exert an upward "pull" on resale prices for used vehicles—meant that changes in prices for new automobiles could influence scrappage decisions by older cars' owners. As a result, he hypothesized, emissions regulations that raised production costs and sales prices of *new* vehicles might retard the scrappage and replacement of older models sufficiently to offset the reduction in criteria emissions from introducing cleaner new models into the vehicle fleet. Gruenspecht's research produced evidence that the increase in new car prices resulting from manufacturers' compliance with the 1980-81 federal emissions standards could be sufficient to have this effect.

Following Gruenspecht's early efforts, several more recent studies have further investigated the determinants of vehicle scrappage, often focusing on the role that fuel prices play in shaping the relative value, and therefore the price, of used vehicles (Li, Timmins, & von Haefen, 2009; Sallee, West, & Fan, 2010; Allcott & Wozny, 2014; Busse, Knittel & Zettelmeyere, 2013; Jacobsen and van Benthem, 2015).

B. Model Used in this Study

The vehicle scrappage model used here is based on well-established economic theory and empirical evidence on the response of owners' decisions about retiring (or "scrapping") used vehicles to changes in economic factors. The model estimates a relationship between new car and truck prices and scrappage or retirement rates for cars and trucks of different model year vintages at each age during their lifetimes.

This study estimates a "reduced-form" scrappage model using aggregate scrappage rates by type (car or truck) for the individual vehicle model years making up the U.S. passenger vehicle fleet over the 2002-2016 period (rather than the scrappage rates for individual vehicle models originally employed by Gruenspecht). Updating results from earlier scrappage studies that analyzed the scrappage response to changes in new vehicle prices is necessitated by increases in the expected lifetimes and average ages of passenger vehicles that have occurred over time. We also update the methodology to incorporate techniques of recent studies to better isolate the relationship of new vehicle prices on scrappage behavior.

1. Basic Theory of the Model

A vehicle's owner will retire the vehicle from service and sell it for its scrap value if its value in working condition exceeds its scrap value by less than the expected cost of repairs necessary to maintain it in working condition. Since the expected cost of these repairs depends on how long a vehicle has been in service as well as on the materials and manufacturing technology employed when it was produced, the probability that it will be scrapped is likely to depend on both its original model year and its age. To some extent, a vehicle's age may simply be a surrogate measure of its accumulated usage, although its age per se may also affect its sale value in working condition and thus the likelihood that it will be retired.

At the aggregate or fleet-wide level, the scrappage rate among a "cohort" of vehicles in service (measured by the proportion of those in service at the beginning of a year that are retired or scrapped before the year ends) will thus depend on both their model year and their age during that year. The scrappage rate will also reflect other factors that affect the value of repairing and operating a used vehicle as opposed to scrapping the vehicle. Most notably, because prices for new vehicles are in turn an important influence on prices for used vehicles of different ages, scrappage rates are likely to be affected by changes in new vehicle prices and the myriad factors that determine them (including manufactures' costs for complying with government regulations).

Finally, scrappage rates for all model years in service are also likely to be affected, although not necessarily uniformly, by changes in other economic variables such as employment or personal incomes. This occurs because keeping used vehicles in service longer provides a temporary mechanism for accommodating increases in total demand for motor vehicle travel that result from changes in economy-wide conditions. Extending the service lifetime of a used vehicle in order to accommodate increased travel demand is accomplished by deferring its retirement beyond the age at which it would otherwise have occurred, a response that reduces the aggregate scrappage rate for vehicles of various ages.

2. Model Variables and Data Sources

The data used to develop this model of these empirical relationships include scrappage rates calculated from U.S. annual vehicle registration data for the years 2002 through 2018. We rely on registrations data for passenger cars and light trucks provided from *IHS Markit* that reflects the number of registered vehicles on the road (i.e., vehicles in operation) as of January 1st of each calendar year in our sample. For each calendar year from 2002-2018, we use this registration data to calculate scrappage rates for vehicles of ages 4 through 19 years, and an overall scrappage rate for vehicles that are 20 years and older. The scrappage rate is measured as the decrease in registered vehicles over the year divided by the number of registered vehicles at the beginning of the year. Note that we calculate separate scrappage rates for passenger cars and light trucks. While the specific types of vehicles included in these registration data - and thus in the scrappage rates used to develop this model - vary over the extended period covered by this study, for most of those periods they closely match those encompassed by the federal government's GHG standards and CAFE standards.

Prices for new cars and trucks are based upon new car and new truck prices indices from the Bureau of Labor Statistics (BLS 2018). These indices make quality adjustments to the new vehicle prices—this would be a limitation for assessing the sensitivity of scrappage to changes in price alone, but in the context of changing prices and fuel economy simultaneously (as under alternative CAFE standards), it is the change in quality adjusted price that is more relevant. Consistent with this choice of price variable in the scrappage model, we use quality adjusted prices in implementing the results of the scrappage model within the Fleet Population Model described in Appendix D. We scale the indices to 2016 dollars using the average expenditure on a new cars and new trucks in 2016 as reported by the Bureau of Economic Analysis (BEA 2018).

3. Model Form and Estimation

The specific mathematical form of the scrappage model employs the measure

$$\ln\left(\frac{s}{1-s}\right) \tag{12}$$

as its dependent variable, where s is the aggregate scrappage rate for vehicles of an individual model year at a specific age and of a specific type (car or light truck), and ln(.) denotes the natural logarithm. This transformation of the scrappage rate, sometimes called the "logit" of the scrappage rate, converts a measure bounded by the values zero and one—and in practice varying over a much narrower range—to one spanning a wider range of values. Using the transformed value of the scrappage rate as the model's dependent variable allows the estimated coefficients to exhibit desirable statistical properties.

The estimation equation regresses this dependent variable against the variable of interest, new prices by vehicle type, as well as a rich set of fixed effects similar to those employed in the Jacobsen-van Benthem study (2015). Specifically, we use the following regression equation for scrappage rates s by vehicle type t, age a, and calendar year y.

$$\ln\left(\frac{s}{1-s}\right)_{t,a,y} = \beta_{y,t}YearType + \beta_{a,t}YearAge + \gamma NewPrice_{t,y} + \varepsilon \tag{13}$$

For example, the scrappage of model year 1995 trucks in calendar year 2005 would be determined by the price of a new truck in 2005 along with a fixed effect for trucks of all ages in 2005 and a fixed effect for all age 10 vehicles in 2005. The rich set of fixed effects serve to absorb the complicating effects of the various macroeconomic factors that exert differential effects on scrappage behavior of different types and ages of vehicles.

Note that the results of the regression model using the logit transformation can be transformed back into an estimated relationship between the scrappage rate itself and the explanatory variables. Specifically, the elasticity of scrappage with respect to new vehicle prices for a vehicle of age *a* and type *t* will be

$$\varepsilon_{a,t} = \gamma * \boldsymbol{NewPrice_t} * (\mathbf{1} - s_{a,t}) \qquad \textbf{(14)}$$

where is the coefficient on new price from the regression and *s* is the scrappage rate.

4. Statistical Results

The resulting model performs well in explaining variation among scrappage rates across the wide range of model years and extended historical period spanned by the underlying data. Table C-1 presents the statistical coefficient estimates and other results of the estimated model in detail.

Table C-1. Scrappage Regression Results

Dependant Variable	ln[s/(1-s)]		**R-Sqaured**	0.9997
Sample Period	2002-2016			
Number of Observations	510		**Root MSE**	0.0643
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**p > |t|**
New Vehicle Price	-0.065	0.002	-29.791	0.0000
Categorical Dummies	**# of dummies**		**F-statistic**	**p > |F|**
Year*Type	30		360.726	0.0000
Year*Age	254		7085.075	0.0000

Source: NERA calculations as explained in text.

The coefficient on new vehicle price has the expected direction and is very highly significant (t = -29.791). Using the equation above, we translate this coefficient into elasticities of scrappage with respect to new vehicle price. These elasticities are shown in Table C-2.

Table C-2. Scrappage Elasticities with Respect to New Vehicle Price by Vehicle Age

	Age-Specific Scrappage Rates		Elasticity of Scrappage with Respect to New Vehicle Price	
	Cars	Light Trucks	Cars	Light Trucks
Age 4	0.029	0.011	-1.587	-2.336
Age 5	0.032	0.014	-1.581	-2.329
Age 6	0.035	0.015	-1.576	-2.327
Age 7	0.042	0.019	-1.565	-2.317
Age 8	0.048	0.026	-1.555	-2.301
Age 9	0.055	0.030	-1.545	-2.290
Age 10	0.063	0.037	-1.531	-2.274
Age 11	0.075	0.045	-1.512	-2.255
Age 12	0.087	0.050	-1.493	-2.243
Age 13	0.100	0.059	-1.471	-2.223
Age 14	0.117	0.073	-1.443	-2.190
Age 15	0.137	0.081	-1.410	-2.170
Age 16	0.149	0.093	-1.391	-2.141
Age 17	0.168	0.099	-1.360	-2.128
Age 18	0.173	0.105	-1.352	-2.114
Age 19	0.189	0.101	-1.326	-2.124
Age 20+	0.200	0.114	-1.307	-2.091

Source: NERA calculations as explained in text.

5. Using the Scrappage Model to Estimate Fleet Population Effects

We use the estimates of the effects of changes in prices (adjusted for utility as described in Appendix B) due to the alternative standards in conjunction with the age-type-specific effects of new vehicle prices on scrappage rates produced by this model to simulate future changes in the age distribution of the vehicles in the national fleet. Specifically, we calculate the changes in scrappage rates for vehicles of each age from four to 20+ predicted by the model's elasticity estimates to result from the specified increases in the average sales price of new cars and light trucks. We assume that scrappage rates for vehicles three years old and less would not change in response to higher prices for new vehicles.

These overall age-specific changes in scrappage rates due to each of the scenarios are then applied to scrappage rates for vehicles of each age in the baseline projected vehicle populations to produce estimates of the changes in vehicle populations due to the CAFE standards in the studied regulatory scenarios.

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Appendix D: Fleet Population Model

The fleet population model combines the results of the New Vehicle Market Model and the Scrappage Model to determine the impacts of the alternative standards on the overall passenger car and light truck fleet for MY 2021-2029.

A. Baseline Scenario

We develop a detailed baseline forecast of the U.S. vehicle fleet population based upon the vehicle population projections in EPA's MOVES vehicle emission inventory model, as implemented by Trinity. The MOVES model includes projections of the vehicle fleet organized by vehicle type and vintage for each of the relevant years. These fleet projections are based on information from the U.S. Energy Information Administration's (EIA) Annual Energy Outlook (AEO) 2014.[25] The AEO2014 projections reference case assumes the augural standards remain in place. All fleet population effects, described in the next section, are modeled as adjustments to this baseline fleet projection.

Table D-1 provides information on the baseline fleet for our analysis period (2017-2050). Note that our vehicle population only includes vehicles of MY 2029 and earlier. Figure D-1 provides a snapshot of the baseline fleet for 2030. This snapshot provides information on the underlying vehicle mix in terms of vehicle type (passenger car or light trucks) and vintage.

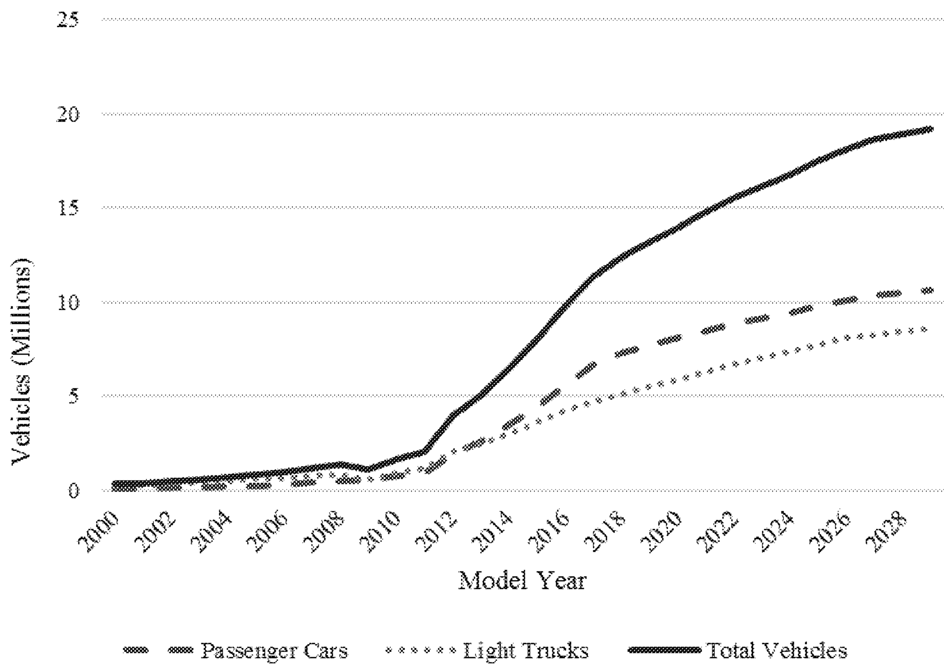
Table D-1. Baseline Fleet by Calendar Year (Millions of Vehicles)

	2017	2020	2025	2030	2035	2040	2045	2050
Passenger Cars	132.7	136.2	142.3	139.2	93.2	47.9	14.7	3.1
Light Trucks	106.9	109.7	114.7	112.2	75.8	43.0	20.4	8.0
Total Vehicles	**239.6**	**246.0**	**257.0**	**251.4**	**168.9**	**90.8**	**35.1**	**11.1**

Note: Consistent with the modeling reported by NHTSA/EPA in the PRIA, our analysis only considers MY 2029 vehicles and earlier.
Source: EPA MOVES 2014b (2018a).

[25] EPA MOVES 2014b (2018b).

Figure D-1. Baseline Vehicle Fleet by Model Year, for 2030



Source: EPA MOVES 2014b (2018a)

B. Changes in Existing Fleet due to New Vehicle Sales

NERA applied the results from the New Vehicle Market Model to the baseline fleet projections for MY 2017 to MY 2029 to estimate the impacts of changes in the new vehicle market due to the alternative CAFE standards. The New Vehicle Market Model allows us to estimate the percentage change in new vehicle sales for passenger cars and light trucks for each model year for which we have CAFE Model information on changes in vehicle costs and fuel economy (i.e., MY 2017 to MY 2032). We apply these percentage changes to model the impacts on new vehicle sales. For example, for the 2021 passenger car fleet, we adjust the number of MY 2021 passenger cars included in the baseline MOVES fleet, by the percentage changes in new vehicle sales that we estimate for each of the three CAFE alternatives using the results of the New Vehicle Market Model for MY 2021. We then carry forward that adjusted number of MY 2021 vehicles to the 2022 fleet, using the same process for the subsequent model year fleets through 2032. Note that only the costs and benefits associated with model years up to MY 2029 are included in the net benefits analysis.

C. Changes in Existing Fleet due to Scrappage Effects

NERA applied the results from the Scrappage Model to the baseline fleet projections for calendar years 2017-2050 to estimate the impacts of changes in vehicle scrappage rates due to increased new vehicle prices. The Scrappage Model allows us to separately estimate the impacts of changes to net new vehicle prices due to the alternative standards on the used vehicle population for passenger cars and light trucks for MY 1977 to MY 2029. We apply these estimated scrappage rates by vehicle age to the relevant model years in the baseline MOVES fleet population for each year.

Since our net benefits estimation considers the operation of these vehicles through calendar year 2050, this analysis requires assumptions about new vehicle prices and scrappage behavior beyond the years modeled in the CAFE and New Vehicle Market models. We assume that the percentage price difference that exists in the last year for which compliance is modeled in the CAFE Model (i.e., 2032) persists through to calendar year 2050. For example, if new vehicle prices are projected to be 3% higher in 2032 under the augural standards compared to another regulatory alternative, we assume prices will remain 3% higher in calendar years 2033-2050 and the price effects on scrappage will continue in those calendar years. As a sensitivity test, we assumed instead that new vehicle price effects would cease completely and scrappage rates would be identical across regulatory scenarios in calendar years 2033-2050; the net benefits results were not significantly affected by this sensitivity case.

D. Combined Effects on Fleet Population

The separate changes in new vehicle sales and changes in scrappage rates would lead to differences in the overall fleet size for the CAFE standard alternatives. The net effects of these two changes did not have a substantial effect on the overall fleet population under any of the three CAFE alternatives (never more than 0.25% change in fleet size compared to the augural standards).

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Appendix E: Vehicle Miles Traveled (VMT) Model

This appendix provides information on the VMT Model developed by NERA. The VMT Model includes the effects of two changes from the baseline values (Augural standard) due to the CAFE alternatives: (1) effects of changes in the vehicle fleet; and (2) effects of changes due to rebound effect.

A. Changes in VMT due to Age and Size of Fleet

The alternative standards affect both the numbers of new vehicles in the fleet (through impacts on new vehicle sales) and the numbers of old vehicle in the fleet (through impacts on scrappage rates). Less-stringent standards, for example, lead to greater new vehicles sales and greater used vehicle scrappage. These effects combine to produce a fleet with relatively more new vehicles than old vehicles under less-stringent standards. Since newer vehicles are typically driven more miles per year than older vehicles, this change in fleet composition can affect total fleet VMT, increasing VMT for less-stringent standards.

If the scrappage effect is larger than the sales effect, the combined effects may produce a smaller fleet under less-stringent standards. For example, if two additional used vehicles are retained for each lost new vehicle sale, the combined VMT of the two used vehicles may outweigh the lost VMT of the new vehicle. Changing fleet size can also affect total VMT.

The net effect of these two changes in the vehicle fleet on VMT was relatively small—the overall effect was never more than 0.02% change relative to VMT under the augural standards for any of the three CAFE alternatives.

B. Changes in VMT due to the Rebound Effect

Improvements in energy efficiency decrease the cost of energy consumption and thus lead to an increase in energy use; this well-known effect is called the "rebound effect." In the context of improvements in motor vehicle fuel efficiency, the rebound effect is defined as the elasticity of VMT with respect to fuel efficiency improvements, i.e., the percentage change in VMT associated with a one-percent change in fuel efficiency. (Reported elasticity estimates typically are multiplied by 100 so the rebound effect is expressed as a percentage, e.g., an elasticity of 0.2 is translated into a rebound effect of 20 percent, meaning that the percent increase in VMT is 20 percent of the percentage improvement in fuel efficiency.) Empirical estimates of the rebound effect are often based on estimated changes in VMT with respect to changes in fuel cost per mile or fuel price.

The VMT Model is based upon an evaluation of alternative estimates in prior studies. This is the approach taken by NHTSA/EPA in the PRIA.

1. Rebound Studies

NERA developed a table listing rebound estimates in the literature, drawing on the lists of studies cited by EPA and NHTSA in NHTSA/EPA's PRIA (2018b) and the EPA Proposed

Determination Technical Support Document (2016).[26] As in the PRIA, we focus on estimates of the long-run rebound effect.[27]

Table E-1 lists the studies in the NERA review. For each study, the table includes columns showing information on (a) the rebound effect range and (b) a most-likely value (if any) or an average value (if not most-likely value). The final rows of Table E-1 show the overall median and mean values across all studies based upon most-likely or average values. The mean rebound effect is 26% and the median rebound effect is 22%.

[26] E.g., see Section 3.4.2 of the EPA Proposed Determination (2016) and Section 8.9.6 of the NHTSA/EPA PRIA (2018b).

[27] See p. 968 of NHTSA/EPA PRIA (2018b).

Table E-1. Estimates of the Long-Run Rebound Effect in Various Studies

Author (Year)	Range	Suggested Value or Average Value	Time Period
Mayo & Mathis (1988)	26%	26%	1958-1984
Gately (1992)	9%	9%	1966-1988
Greene (1992)	5 - 19%	12%	1966-1989
Jones (1993)	30%	30%	1966-1989
Schimek (1996)	21 - 29%	25%	1950-1994
Greene, Kahn & Gibson (1999)	23%	23%	1979-1994
Pickrell & Schimek (1999)	4 - 34%	19%	1995
Puller & Greening (1999)	49%	49%	1980-1990
Haughton & Sarkar (1996)	22%	22%	1973-1992
West (2004)	87%	87%	1997
Small & Van Dender (2005)	22%	22%	1966-2001
Small & Van Dender (2007)	11%	11%	1997-2001
Barla et al. (2009)	20%	20%	1990-2004
Bento (2009)	21 - 38%	34%	2001
Wadud et al. (2009)	1 - 25%	13%	1984-2003
Hymel, Small & Van Dender (2010)	24%	24%	1966-2004
Hymel, Small & Van Dender (2010)	16%	16%	1984-2004
West and Pickrell (2011)	9 - 34%	22%	2009
Su (2012)	13%	13%	2009
Anjovic and Haas (2012)	44%	44%	1970-2007
Greene (2012)	8 - 12%	10%	1967-2006
Linn (2013)	20 - 40%	30%	2009
Frondel and Vance (2013)	46 - 70%	58%	1997-2009
Liu et al. (2014)	40%	40%	2009
Gillingham (2014)	22 - 23%	22%	2001-2003
Weber and Farsi (2014)	19 - 81%	50%	2010
West et al. (2015)	0%	0%	2009
Hymel & Small (2015)	18%	18%	2000-2009
DeBorger (2016)	8 - 10%	9%	2001-2011
Stapleton et al. (2016)	9 - 36%	19%	1970-2011
Stapleton et al. (2017)	14 - 30%	26%	1970-2012
Mean:		**26%**	
Median:		**22%**	

Notes: The mean and median were calculated using mid-points or suggested values for studies in which a range is reported.

Source: Studies included in Section 3.4.1 of the EPA Proposed Determination TSD (2016) and Table 8-8 of NHTSA/EPA PRIA (2018b). Note that NERA did not include the value of 0 included for the Goldberg (1996) study, as this estimate was based on the lack of statistical significance rather than a rebound estimate.

2. Average Rebound Values for Study Grouping

Differences in these studies can be evaluated based upon groups organized by date of the study and by geography. We consider whether there are systematic differences by decade and by broad geographic groupings. We also consider the potential changes over time due to future growth in per capita income.

The studies listed in Table E-1 were published between 1988 and 2017 and provide estimates of the long-run rebound effect ranging from zero to 87 percent. Grouped by decade, the studies do not appear to show a clear temporal trend in rebound estimates: (a) for studies published between 1990 and 1999, the average rebound effect is 24 percent; (b) for studies published between 2000 and 2009, the average rebound effect is 31 percent; and (c) for studies published between 2010 and 2017, the average rebound effect is 25 percent.

The studies include both domestic and international studies. Seven of the 30 studies in Table E-1 use data from regions outside of the United States (Canada, Great Britain, and the EU); the average rebound effect for these studies is 32 percent. Twenty-three of the 30 studies use U.S. data; the average rebound effect for these studies is 24 percent.

Several studies (e.g. Greene 2012 and Hymel & Small 2015) posit that the rebound effect should decrease as per capita incomes increase. The PRIA includes an evaluation of this issue.

3. Rebound Effect Used in the VMT Model

We use a rebound value of 20 percent in the VMT Model. This choice reflects our best professional judgement accounting for the results from the existing studies as well as the possibility that the rebound effect might decline in the future due to potential increases in per capita income.

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Appendix F: MOVES Model

This appendix describes how Trinity used the U.S. Environmental Protection Agency (EPA) Motor Vehicle Emissions Simulator (MOVES) vehicle emissions model to estimate the change in CO_2-equivalent and criteria pollutant emissions for the U.S. vehicle fleet due to the alternative CAFE standards. MOVES was developed by EPA to estimate criteria pollutant and CO_2-equivalent emissions from U.S. on-road motor vehicles over nationwide, regional and localized scales under a wide range of fleet characteristics, ambient and operating conditions. MOVES is based on exhaustive vehicle emission testing measurements collected under both laboratory and in-use conditions and is designed to estimate on-road vehicle fleet emissions and changes over time from on-going changes to federal new vehicle emission standards as well as local control programs.

A. Overview of MOVES Model

EPA regularly updates the model, generally as additional vehicle emission testing study data become available or when new vehicle emission certification or fuel standards are promulgated. The latest version of MOVES, MOVES2014b (released in August 2018) was used by Trinity to perform the analysis of changes in light-duty vehicle fleet tailpipe[28] emissions under different CAFE standard alternatives. Although NHTSA's vehicle emissions analysis presented in the NPRM was based on an earlier version, MOVES2014a, the on-road vehicle emissions portions of both MOVES versions are identical. (MOVES also estimates emissions from off-road vehicles and equipment and these elements were updated in MOVES2014b.)

Differences in vehicle emissions under various CAFE alternatives between this analysis and those published in the proposed rulemaking (Appendix D of the DEIS) are the result of several primary and secondary factors as follows:

- *Primary Differences*. Primary differences arise from the different input fleet forecast data used in the NERA/Trinity analysis versus that utilized by NHTSA within the CAFE Model. Specifically, NHTSA estimates fleet changes (projected sales, car vs. truck fleet shifts, scrappage-related age distribution impacts and VMT impacts from the rebound effect) using those internal modeling elements within the CAFE Model. The NERA/Trinity analysis used fleet forecasts and composition generated by NERA's New Vehicle Market, Scrappage, VMT and Fleet Population models to determine CAFE standard alternative vehicle fleet impacts.

- *Secondary Differences*. Small differences in emissions between NHTSA and NERA/Trinity estimates may have resulted from the fact that the NERA/Trinity MOVES runs were executed for a Yearly time aggregation level.[29] MOVES can be executed at

[28] MOVES only estimates on-road (i.e., tailpipe) vehicle emissions. Upstream emission impacts from different CAFE standard alternatives were estimated using a separate model, GREET, and are discussed in Appendix G of the report.

[29] MOVES can be executed at different time aggregation levels for which emissions are individually calculated between Yearly and Hourly levels. This Time Aggregation run option significantly affects the model's execution time. Hourly level executions can take between and 25-50 times longer to complete than Yearly level runs, depending on the pollutants and emission processed included in the run. There was not sufficient time to complete a full set of Hourly time aggregation level runs within the NPRM comment period. A comparison of Yearly vs. Hourly time aggregated outputs for one CAFE scenario (augural

different time aggregation levels from Yearly down to Hourly calculation levels. Hourly-based emissions (summed to annual estimates) tend to be nominally higher than those based on the Yearly Time Aggregation option. MOVES can only calculate evaporative VOC emissions when run in Hourly mode (to account for diurnal temperature impacts). Although evaporative VOC emissions are a significant fraction of total VOC emissions for late-model light-duty gasoline vehicles, their impact on the overall net cost-benefit analysis is believed to be marginal. As noted in both the PRIA and DEIS, the agencies also excluded evaporative VOC emissions from their tailpipe emission estimates.

B. MOVES Inputs and Run Configuration Options

Table F-1 lists the MOVES modeling settings used to generate light-duty vehicle U.S. fleet emissions impacts under each CAFE standards alternative evaluated. It is divided into two sections. The first model command file (called a "Runspec" in MOVES terminology) options that were used are enumerated. The term "Source Use Type" in these tables is a use type vehicle categorization used by MOVES (to reflect how vehicles operate differently), rather than regulatory class categorization scheme. Source Use Types encompassing the light-duty vehicle fleet include Passenger Cars (which align with the passenger car regulatory category), Passenger Trucks and Light Commercial Trucks, which span the 8,500 lb GVW cutoff between the light- and heavy-duty vehicle regulatory classes (as well at the 10,000 lb GVW limit for medium-duty passenger vehicles under CAFE). MOVES uses an internal allocation scheme to map between the Source Use Type and Regulatory Class-based vehicle categories.[30] Thus as listed under the Output Emissions Detail setting in Table F-1, emissions outputs by regulatory class were selected to align with the passenger car and light truck CAFE definitions (including Class 2a medium-duty passenger vehicles).

standards) was performed. Tailpipe emissions under the Yearly time aggregation were found to be 2-14% lower than those from the Hourly option run across all pollutants with the exception of VOC as explained above.

[30] Table A, "MOVES2014, MOVES2014a and MOVES2014b: Technical Guidance, Using MOVES to Prepare Emission Inventories for State Implementation Plans and Transportation Conformity," U.S. Environmental Protection Agency, Report No. EPA-420-B-18-039, August 2018.

Table F-1. MOVES Modeling Settings

Setting	Value
Runspec/Command File Options	
MOVES Version	MOVES2014b-20180726
Time Aggregation Level	Yearly
Years	2016-2030, 2035, 2040, 2045, 2050
Months/Hours/Days	All
Geographic Bounds	Nationwide (entire U.S.)
Vehicles	Light Commercial Truck, Passenger Truck, Passenger Car. All Fuel Types.
Road Types	All
Pollutants (criteria)	NOx, CO, VOC, SO_2, and $PM_{2.5}$ and PM_{10} (Total, brake wear, and tire wear)
Pollutants (greenhouse)	CO_2 eq, CO_2, Methane, Nitrous Oxide
Output Emissions Detail	Outputs disaggregated by Model Year, Fuel Type, Emission Process, Source Use Type and Regulatory Class
Input Database Elements	
Vehicle Type VMT	Annual VMT by Source Type from NERA modeling
Source Type Population	Populations by Source Type from NERA modeling
Age Distribution	Vehicle population fractions by age (years) for each Source Use Type and calendar year combination

Below these "Runspec" options, input database elements that were changed from MOVES nationwide default values are also listed in Table F-1. These inputs include VMT by Source Use Type and calendar year, vehicle populations by Source Use Type and calendar year and vehicle age distributions and revised the revised fleet activity forecast for each CAFE alternative developed by NERA. The Vehicle Type VMT and Source Type Population inputs reflect NERA's accounting for the rebound effect and vehicle choice modeling, respectively. The Age Distribution input accounts for scrappage-related effects.

Unless explicitly listed in Table F-1, all other MOVES inputs and run settings were based on MOVES default values.

C. MOVES Post-Processing

The MOVES model is built around the MySQL relational database platform. As a result, its outputs (in the form of MySQL databases and tables) were exported and post-processed into spreadsheets for easier dissemination, and to perform various summary tabulations on the model outputs (for example summing emissions by model year for a calendar year fleet).

Beyond the exporting and summary tabulation elements, CO_2 emission adjustments were applied to MOVES outputs for all CAFE alternatives except the augural standards scenario. Unlike the CAFE Model, MOVES does not directly evaluate CO_2-equivalent emission impacts of alternative CAFE standards; CO_2-equivalent outputs from MOVES reflect the adopted augural standards. Adjustments were thus made to MOVES CO_2 emission outputs to reflect fuel economy/CO_2 emission rate differences between the augural standards and the CAFE alternative evaluated. These adjustments were based on ratio of the alternative CAFE scenario standard to that of the augural standards, the "reference" fuel economy/CO2 hardcoded into MOVES. These adjustment ratios were calculated by vehicle type (passenger car and light truck) and model year. They were based on the industry fleet average required fuel economy (in miles per gallon) contained in the "Standard" field in the Compliance Report output for the mainstream "Scenario 1-4 CAFE Model runs described in the CAFE Model Appendix (Appendix A).

D. References

National Highway Traffic Safety Administration (NHTSA), 2018. "Draft Environmental Impact Statement: The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Year 2021-2026 Passenger Cars and Light Trucks." *Docket No. NHTSA-2017-0069*. July.

U.S. Environmental Protection Agency (EPA). 2018. "MOVES2014, MOVES2014a and MOVES2014b: Technical Guidance, Using MOVES to Prepare Emission Inventories for State Implementation Plans and Transportation Conformity," *Report No. EPA-420-B-18-039*, August.

U.S. Environmental Protection Agency (EPA) and National Highway Traffic and Safety Administration (NHTSA), 2018b. "Preliminary Regulatory Impact Analysis (PRIA): The Safer Affordable Fuel-Efficient (SAFE) Vehicles rule for Model Years 2021–2026 Passenger Cars and Light Trucks." July.

Appendix G: Upstream Emissions Modeling

This appendix provides information on the modeling used to develop estimates of upstream emissions due to the alternative CAFE standards considered in this study. Upstream emissions refer to the emissions associated with fuel production including crude oil production, fuel refining, and fuel distribution and storage. We first provide a discussion of the methodology used by NHTSA/EPA as described in the PRIA, on which our estimates are based. We then provide information on how we implement the NHTSA/EPA PRIA methodology using our estimates of changes in fuel consumption as summarized in Figure 6.

A. NHTSA/EPA PRIA Upstream Emissions Factors

To develop upstream emissions estimates we rely on the upstream emissions factor estimates used by NHTSA/EPA in the PRIA that are included in the CAFE Model parameters file. The PRIA notes that the upstream emission factors relied on by the agencies for each fuel type are based on the energy content and emission rates per unit of fuel energy refined and distributed, as developed using the Greenhouse Gases and Regulated Emissions in Transportation (GREET) Model developed by Argonne National Laboratories.

The upstream emissions factor values included in the CAFE model parameters files include upstream emissions factor estimates (g/MMBtu) for CO, VOC, NO_X, SO_X, $PM_{2.5}$, CO_2, CH_4, and N_2O. Separate upstream emissions values are reported for the following activities for each relevant fuel type: petroleum extraction, petroleum transportation, petroleum refining, and fuel transportation, storage, and distribution (TS&D).

For the criteria pollutant emissions, (i.e., pollutants for which ambient air quality standards have been developed or precursor pollutants), the factors associated with these activities are then scaled to reflect the share of such activities that are expected to occur within the United States. For gasoline for example, the NHTSA/EPA PRIA states that it assumed that 50% of increased gasoline consumption would be supplied by increased domestic refining and that 90% of this additional refining would use imported crude petroleum. The NHTSA/EPA PRIA criteria pollutant upstream values accordingly include 5% of the total petroleum extraction and transportation emissions, 50% of the total petroleum refining emissions, and 100% of the fuel TS&D emissions. The PRIA indicates that estimates of criteria pollutant emissions are for domestic emissions only.[31]

For CO_2 and CH_4, the NHTSA/EPA PRIA emissions factors do not include any domestic scaling, but rather include all relevant upstream emissions regardless of where the actual upstream activity is assumed to take place. The PRIA does not include an explanation of this treatment of the two greenhouse gas (GHG) emissions, although it presumably reflects the global nature of the effects of GHG emissions. Note that the social cost of carbon (SCC) values used in the PRIA to develop dollar values include only the domestic valuation of GHG emissions.

There is one exception in the treatment of GHG emissions in the PRIA. For N_2O, the upstream emissions factors include the same scaling as the criteria pollutants. We presume this is an error,

[31] See e.g., footnote 657 on p. 1215 or p. 1303, NHTSA/EPA PRIA (2018b)

as N_2O is a GHG whose impacts should presumably be treated the same as CO_2 and CH_4. The PRIA does not include an explanation for why N_2O is treated differently than the other GHGs.

B. NERA Implementation of NHTSA/EPA PRIA Upstream Emissions Factors

We develop upstream emissions estimates for the alternative CAFE standards by multiplying the NHTSA/EPA PRIA upstream emissions factors by the changes in fuel consumption that we estimate based on our fleet population and VMT modeling. We outline the key implementation steps and adjustments we make below.

1. Adjustments to NHTSA/EPA PRIA Upstream Emissions Factors

a. Convert Factors to Grams per Gallon

We convert these values (which are in grams per million BTUs) to grams per gallon based on the energy density assumptions for each relevant fuel type included in the CAFE Model parameters file. These energy density assumptions are summarized in Table G-1 below.

Table G-1. NHTSA/EPA PRIA Energy Density Assumptions by Fuel Type (Btu/gallon)

Fuel Type	Energy Density (Btu/gallon)
Gasoline	115,219
Diesel	82,294
Ethanol-85	129,488

Source: CAFE Model parameters file available on NHTSA website.

b. Adjust Ethanol-85 Import Assumptions

The CAFE model parameters file notes that for Ethanol-85 (E85) the share of fuel savings leading to reduced domestic fuel refining would be 0.075 (i.e., a 1-gallon reduction in E85 consumption would decrease domestic fuel refining by 0.075 gallons). The model parameters file notes that this figure is calculated as 15% of the domestic fuel refining assumption for gasoline (i.e., E85 contains 15% petroleum content, and NHTSA/EPA assume in the PRIA that a decrease in gasoline consumption would lead to a 50% reduction in domestic fuel refining). Note however that the NHTSA/EPA PRIA parameters file indicates that within this 0.075 reduction in domestic fuel refining, the share of domestic refining from domestic crude oil for E85 would be 0.015 and the share of domestic refining from imported crude oil for E85 would be 0.135. This sum (share of domestic crude + share of imported crude) does not add to one, which we presume is an implementation error due to an effective double counting of the 15% E85 adjustment. Note that this error would somewhat understate the upstream emissions estimates associated with changes to E85 consumption. To avoid understating the emissions impacts associated with E85, we use the 0.075 domestic fuel refining assumption and then apply the same assumption related to the relative share of domestic crude oil (10%) and imported crude oil (90%), as that used for gasoline and diesel above.

c. Adjust N_2O Upstream Emissions Factors

As noted, the upstream emissions factors used by NHTSA/EPA PRIA for N_2O include the same scaling to estimate domestic emissions only as the criteria pollutants. We presume this is in error, as N_2O is a GHG whose impacts should be treated the same as CO_2 and CH_4. The PRIA does not include an explanation for why N_2O is treated differently than the other GHGs. Accordingly, we remove any domestic scaling from the N_2O upstream emissions factors, such that the N_2O emissions factors are consistent with the other GHGs.

2. NERA-Adjusted Upstream Emissions Factors

Table G-2 summarize the factors we rely on below by fuel type for each relevant pollutant. For ease of exposition, results are provided for every fifth year. Note that for the emissions tables included in Chapter III of this report, we convert CH_4 and N_2O to CO_2 equivalents based on the as an assumed global warming potential (GWP) value for CH_4 of 25 and a GWP of 298 for N_2O as reported by EPA (2017).[32] To develop the upstream emissions estimates we multiply these upstream factors by the estimated changes in fuel consumption due to the alternative standards as provided in Figure 6.

[32] See EPA (2017) "Greenhouse Gas Equivalencies Calculator." https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Table G-2. Upstream Emissions Factors by Fuel Type (grams/gallon)

Calendar Year	Source	CO	VOC	NO_X	SO_2	PM	CO_2	CH_4	N_2O
2020	Gasoline	0.8	2.8	1.8	1.6	0.1	2,362.6	21.2	0.5
	Diesel	0.4	0.3	0.8	0.5	0.1	1,829.7	22.0	0.0
	E85	2.2	4.4	5.9	4.6	0.4	246.7	1.9	0.1
2025	Gasoline	0.8	2.9	1.6	1.2	0.1	2,230.6	19.6	0.3
	Diesel	0.4	0.3	0.8	0.5	0.1	1,829.7	22.0	0.0
	E85	2.2	4.4	5.9	4.6	0.4	246.7	1.9	0.1
2030	Gasoline	0.8	2.9	1.6	1.2	0.1	2,209.9	19.6	0.3
	Diesel	0.4	0.3	0.8	0.5	0.1	1,809.0	22.0	0.0
	E85	2.2	4.4	5.9	4.6	0.4	246.7	1.9	0.1
2035	Gasoline	0.8	2.9	1.6	1.1	0.1	2,206.4	19.6	0.3
	Diesel	0.4	0.3	0.8	0.5	0.1	1,806.4	22.0	0.0
	E85	2.2	4.4	5.9	4.6	0.4	246.7	1.9	0.1
2040	Gasoline	0.8	2.9	1.6	1.1	0.1	2,200.7	19.6	0.3
	Diesel	0.4	0.3	0.8	0.5	0.1	1,801.2	22.0	0.0
	E85	2.2	4.4	5.9	4.6	0.4	246.7	1.9	0.1
2045	Gasoline	0.8	2.9	1.6	1.1	0.1	2,196.1	19.6	0.3
	Diesel	0.4	0.3	0.8	0.5	0.1	1,796.0	22.0	0.0
	E85	2.2	4.4	5.9	4.6	0.4	246.7	1.9	0.1
2050	Gasoline	0.8	2.9	1.6	1.1	0.1	2,193.8	19.6	0.3
	Diesel	0.4	0.3	0.8	0.5	0.1	1,793.4	22.0	0.0
	E85	2.2	4.4	5.9	4.6	0.4	246.7	1.9	0.1

Note: Values in grams per gallon.
Source: CAFE Model parameters file and NERA adjustments as explained in text.

C. References

U.S. Environmental Protection Agency (EPA), 2017. "Greenhouse Gas Equivalencies Calculator." https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

U.S. Environmental Protection Agency (EPA) and National Highway Traffic and Safety Administration (NHTSA), 2018b. "Preliminary Regulatory Impact Analysis (PRIA): The Safer Affordable Fuel-Efficient (SAFE) Vehicles rule for Model Years 2021–2026 Passenger Cars and Light Trucks." July.

Appendix H: Private Costs and Benefits of Alternative CAFE Standards

This appendix provides information on the data and methods used by NERA to assess changes in consumers' private costs and benefits due to the alternative CAFE standards. The level of CAFE standards stringency will affect both the cost and the driving value of new vehicles through the standards' impact on the application of fuel economy technologies. Greater technology application under more stringent standards, for example, will increase the prices consumers must pay for new vehicles but will also provide consumers with benefits from the higher fuel economy of these vehicles. The following sections describe the specific calculations we use to estimate those costs and benefits across CAFE standard alternatives.

A. Consumer Technology Costs of Increased Fuel Economy

Technology costs are calculated as the retail value of any additional technologies adopted for compliance with CAFE standards, aggregated across all new vehicle sales. The costs of the technologies and the manufacturers' choice of which technologies to apply to each vehicle models are outputs of the CAFE model. For estimating costs of these technologies to consumers, the CAFE model assumes a retail price equivalent (i.e., a "mark-up") of 1.5 for fuel economy technologies.

For a particular model year, the total technology cost due to the CAFE standards is calculated using a similar formulation as that employed by NHTSA/EPA in the PRIA:

$$\boldsymbol{TechCost_{MY}} = \sum\nolimits_{C} \left(\boldsymbol{TechCost_{C,MY}} \times \boldsymbol{Sales_{C,MY}}\right) \tag{15}$$

Where:

$TechCost_{C,MY}$	: The sales-weighted average of retail cost of fuel economy technologies applied for vehicles in class C in model year MY, estimated using technology costs from the CAFE model
$Sales_{C,MY}$	: The sales of vehicles in class C in model year MY

B. Consumer Benefits of Increased Vehicle Fuel Economy

Vehicles with greater fuel economy provide benefits to consumers including (a) potential fuel savings for a given distance of travel, (b) increased mobility through the ability to afford more miles of travel, and (c) time savings of an increased driving range. The estimation of each of these components is described below.

1. Valuation of Changes in Fuel Economy to New Vehicle Purchasers

An improvement to a vehicle's fuel economy provides purchasers with prospective fuel savings over the course of the vehicle's operation. The actual dollar value of those fuel savings to new vehicle purchasers depends upon many uncertain factors, including the potential miles traveled, the potential fuel prices, the number of years of ownership, and the likely opportunity cost of selling the vehicle as a used vehicle. From the new vehicle purchaser's point of view, the present value of potential fuel savings depends on the discount rate they might apply to future fuel savings, which would incorporate the various uncertainties.

To capture this valuation of the prospective fuel savings, we measure the value consumers are observed to place on the prospective fuel savings afforded by improved fuel economy using the estimates of fuel economy changes from the CAFE model and NERA's estimate of consumers' willingness-to-pay for such changes from the New Vehicle Market Model. This estimation is calculated using the equation below.

$$\boldsymbol{ValuationFE_{C,MY,CY}} = \sum\nolimits_{C} \left(\boldsymbol{CPM_{i,C,MY,CY}} - \boldsymbol{CPM_{i,C,2016,CY}}\right) \times \boldsymbol{WTP} \times \boldsymbol{Sales_{i,C,MY}} \qquad \textbf{(16)}$$

Where:

$CPM_{i,MY,CY}$	: The average cost per mile of model year *MY* vehicles in class *C* in calendar year *CY* in scenario *i*
$CPM_{i,2016,CY}$	: The average cost per mile of baseline fleet (i.e., MY 2016) vehicles in class *C* in calendar year *CY* in scenario *i*
WTP	: Consumers' willingness to pay for dollar-per-mile reduction in fuel costs; estimated to be \$694 in the New Vehicle Market Model
$Sales_{i,C,MY}$	: Sales of model year *MY* new vehicles in class *C*

2. Valuation of Changes in Vehicle Miles of Travel

Increased fuel economy lowers the cost-per-mile of travel and allows drivers to afford increased mobility. Specifically, from a baseline level of miles, the decrease in cost-per-mile will lead drivers to increase VMT until the marginal benefit of an additional mile is equal to the marginal cost of the next mile. We estimate the value of these "rebound" miles between the augural standards baseline and the three CAFE alternatives using the costs-per-mile in the two relevant scenarios, as shown in the equation below. Consistent with NHTSA/EPA's treatment of the rebound mobility benefit in the PRIA, this conceptually captures both (a) the value offsetting the fuel cost of traveling those miles and (b) the additional consumer surplus from the fact that the value of these additional miles exceeds the cost.

$$\boldsymbol{ReboundMilesValue_{i,MY,CY}} = \sum \left(\begin{array}{c} \left(\boldsymbol{ReboundMiles_{i,MY,CY}}\right) \times \\ \left(\dfrac{\boldsymbol{CPM_{i,MY,CY}} + \boldsymbol{CPM_{0,MY,CY}}}{\mathbf{2}}\right) \end{array} \right) \qquad \textbf{(17)}$$

Where:

ReboundMiles	: The number of rebound miles traveled by model year *MY* vehicles in calendar year *CY* in scenario *i*
$CPM_{i,MY,CY}$	: The average cost per mile of model year *MY* vehicles in calendar year *CY* in scenario *i*
$CPM_{i,MY,CY}$	: The average cost per mile of model year *MY* vehicles in calendar year *CY* in scenario *i*

For total social benefits from changes in mobility, we aggregate across the values for the model years whose fuel economies are affected by the standards (i.e., MY 2017-2029) and across all calendar years in which these vehicles are driven.

3. Valuation of Changes in Driving Range

Finally, changes in the fuel efficiency of vehicles will affect the driving range for a given quantity of fuel (assuming the sizes of gas tanks do not change). Improved fuel economy would allow consumers to spend less time refueling, providing time saving benefits in addition to the fuel savings and greater mobility benefits discussed above. We follow the formulation used in the NHTSA/EPA PRIA for estimating the value to consumers from reduced refueling time, with one minor difference. Specifically, in the absence of accurate data on fuel tank sizes for vehicle models by model year, we use a simplifying assumption of an average tank size equal to 17 gallons. Using NHTSA's value for average percent of fuel tank refilled of 65%, this translates into a need to refuel every 11.05 gallons. This is used in the following equation to estimate the value of changes in driving range associated with the CAFE standards.

$$\boldsymbol{RefuelValue_{MY,CY}} = \sum \left(\begin{array}{c} \left(\dfrac{\boldsymbol{RefuelTime_{Fixed}} + \dfrac{\mathbf{11.05}}{\boldsymbol{RefuelTime_{Variable}}}}{\mathbf{60}} \right) \times \\ \left(\dfrac{\boldsymbol{G'_{MY,CY}}}{\mathbf{11.05}} \right) \boldsymbol{x\, TravelValue} \end{array} \right) \qquad \mathbf{(18)}$$

Where:

$RefuelValue_{MY,CY,FT}$	: Refueling time benefit for model year *MY* vehicles in calendar year *CY*
RefuelTime	: A fixed component of refueling time; we use NHTSA's value of 3.5 minute
$RefuelTime_{Variable}$	: The variable component of refueling time; we use NHTSA's value of 7.5 gallons per minute
$G'_{MY,CY}$	: Gallons of fuel consumed by model year *MY* vehicles in calendar year *CY*
TravelValue	: Value of travel time per vehicle; we use NHTSA's value of $18.83 per hour

To obtain an estimate of total social benefits from changes in driving range due to the alternative CAFE standards, we aggregate across all model years and calendar years in the analysis.

C. References

U.S. Environmental Protection Agency (EPA) and National Highway Traffic and Safety Administration (NHTSA), 2018b. "Preliminary Regulatory Impact Analysis (PRIA): The Safer Affordable Fuel-Efficient (SAFE) Vehicles rule for Model Years 2021–2026 Passenger Cars and Light Trucks." July.

Appendix I: Crash Costs

This appendix provides information on the data and methods used by NERA to estimate the potential safety externalities associated with the alternative standards. We first include a discussion of our methodology, which we develop based on the NHTSA/EPA PRIA methodology. We then present results for estimates of the safety impacts based on the results of our fleet population modeling.

A. Overview of Methodology

The PRIA considered the effects of three potential factors due to the alternative CAFE standards on vehicle safety:

1. Effects of differences in vehicle mass related to adoption of various technologies.
2. The increase in the pace of consumer acquisition of newer safer vehicles that results from lower vehicle prices associated with technologies to meet less stringent CAFE standards.
3. Decreased driving because of lower fuel economy.

In the following subsections, we first evaluate the likely significance of each of these factors. For the two categories that we determine to be likely significant we then calculate the associated changes in safety costs by implementing the following steps:

1. Translate the fleet changes due to the standards into changes in fatalities.
2. Develop a dollar value estimate of that change in fatalities by applying an appropriate value of statistical life parameter.
3. Calculate the costs associated with changes in non-fatal crash costs as a function of the fatal crash costs.

1. Changes in Vehicle Mass

One way for manufacturers to meet higher CAFE standards is by producing lighter vehicles. If lighter vehicles are also less safe, fuel economy-related changes in vehicle mass may impact vehicle safety.

The NHTSA/EPA PRIA includes a review of studies and an analysis of historical crash data to evaluate the effects of vehicle mass and size on safety. The results of the analysis are shown in Table 11-1 of the NHTSA/EPA PRIA. These results indicate that none of the fatality-increase-per-mass-reduction estimates are statistically significant. Because of the lack of statistical significance and because the NHTSA/EPA PRIA also indicates that the curb weight effects are small relative to the other two effects on crash costs they estimate,[33] we do not consider effects of changes in vehicle mass on crash costs.

[33] Table 11-24 on p. 1414 of PRIA.

2. Changes in Fleet Population

The NHTSA/EPA PRIA indicates that because newer cars have more safety features, an increase in the rate of acquisition of newer vehicles due to a decrease in the price of new vehicles may result in higher safety for the fleet of vehicles. Additionally, lower new vehicle prices mean that old vehicles are scrapped at a higher rate, removing older vehicles with fewer safety features from the fleet. Thus, sales and scrappage effects of less stringent standards combine to produce a newer fleet with safer vehicles, all else equal.

NERA uses the results of the Fleet Population Model as an input in the crash cost methodology from the NHTSA/EPA PRIA to estimate the effects of changes in the age-distribution of the vehicle fleet from the CAFE alternatives on crash costs.

3. Changes in VMT

The NHTSA/EPA PRIA indicates that the number of accidents is related to the VMT driven, with accidents increasing with increasing VMT. For changes in driving due to the rebound effect, however, the NHTSA/EPA PRIA notes that crash costs need not be evaluated because they are included in drivers' decisions to change the number of miles they drive. Because drivers are assumed to be aware of the risk of driving when they make the determination to drive extra miles due to the rebound effect, the miles are driven because they receive an equal and offsetting benefit from driving the miles. Thus, the NHTSA/EPA PRIA assumed that consumers that drive rebound miles fully internalize crash costs. Based on this assumption, crash costs from rebound miles would be included both in societal costs and societal benefits, resulting in zero net societal benefits. Following this logic, NERA does not consider rebound miles in its calculation of crash costs, although we note that changes in rebound miles might lead to crash costs to other drivers, costs that would not be internalized. The NHTSA/EPA PRIA does not provide information to develop estimates of this potential external effect of changes in rebound-related VMT. To the extent that the CAFE alternatives lead to fewer rebound-mile crashes, reductions in external crash costs would lead to social cost savings that are not included in our estimates.

4. Calculating Fatalities

Based on our evaluation of the above criteria, we calculate fatalities associated with changes in acquisition of new vehicles due to the alternative standards. As described below, we rely on the methodology for calculating changes in fatalities as described in the NHTSA/EPA PRIA and CAFE Model documentation, with an adjustment to ignore any effects due to mass change effects.

Note that VMT is an input into the calculation. The section above regarding increased driving has to do with the rebound effect; non-rebound VMT, however, is used as input in determining the number of fatalities.

B. Modeling of Crash Costs in NHTSA/EPA PRIA

NHTSA/EPA use the following equation (Equation 92 from the CAFE Model documentation) to calculate the number of fatalities F for vehicles of a given model year (MY) and fuel type (FT) in a given calendar year (CY).

$$F_{MY,CY,FT} = \sum_{i \in V} \left(\frac{M'_{i,MY,CY,FT}}{1e9} \; x \; MAX(28.58895 + FixedEffect_{MY}, 2) \; x \left(1 + Effect_{SC_i,CW_i} \; x \; \frac{T_{SC_i} - CW_i}{100}\right) \right) \quad (19)$$

The components can be separated to show the effects of the three factors:

$\frac{M'_{i,MY,CY,FT}}{1e9}$	Billions of miles driven by all vehicles of model i: more miles travelled will result in more fatalities
$MAX(28.58895 + FixedEffect_{MY}, 2)$	Vintage fixed effects for number of vehicle related fatalities per billion miles (two, the lowest value seen in the data for fatalities per billion miles, is used as a lower bound). Later model years will have lower (more negative) values for the fixed effect, lowering the fatalities estimates for those newer model years.
$\left(1 + Effect_{SC_i,CW_i} \; x \; \frac{T_{SC_i} - CW_i}{100}\right)$	Curb weight effects by safety class (PC, SUV/Truck, CUV/Minivan). Each class has a "threshold" T_{SCi} representing the boundary between small and large weight effects. Above and below those thresholds, the number of fatalities will change according to the Effect parameter's percent change in fatalities per 100lb change in curb weight.

Parameters used for the model year fixed effects, the safety class thresholds, and the fatality-curb weight elasticity are available in the CAFE Model parameters reference file available on NHTSA's website. The model year fixed effects are estimated in a regression of fatalities per VMT against model year fixed effects and polynomials in vehicle age. For the safety class thresholds and the fatality-curb weight elasticities, the PRIA updated the Kahane (2012), Puckett (2016), and Kindelberger/Draft TAR (2016) analyses that use logistic regressions by vehicle class and crash type to estimate the relationships between fatality per VMT rates and vehicle mass.

C. Overview of NERA Modeling of Crash Costs

NERA followed the methodology for calculating fatalities described by NHTSA/EPA in the PRIA with several changes:[34]

1. The VMT input used is the non-rebound VMT from the Fleet Population model.
2. The effects of curb weight are not included.
3. Since curb weight is not included, it is no longer necessary to aggregate from the individual vehicle level. Note that in the equation below, there is no summation over all vehicles within each model year, calendar year, and fuel type.

[34] As with the other parameters developed by EPA and NHTSA, NERA has not evaluated the underlying data and analysis behind the NHTSA safety analysis; thus the use of these parameters does not constitute confirmation of their validity.

We do not treat vehicles of different fuel types separately because the remaining components of the model are not unique to fuel type. NERA used the following equation:

$$F_{MY,CY} = \frac{MI'_{MY,CY}}{1e9} x\ MAX(28.58895 + Fixed\ Effects_{MY}, 2) \tag{20}$$

The fixed effects for the vintage-specific safety component used in this model are those provided in parameters file that accompanies the PRIA.

D. Methodology for Calculating Results for Fatal Crash Costs

Total fatality crash costs are then calculated using a cost-per-fatality parameter.

$$FatalityCosts_{MY,CY} = F_{MY,CY}\ x\ FatalityCost \tag{21}$$

The PRIA uses $9.9 million as the societal value of an additional statistical fatality. This value is based on the value of a statistical fatality determined in the NHTSA/EPA PRIA, which is derived from data in Blincoe et al. (2015), adjusted to 2016 dollars and updated to reflect the DOT guidance on the value of a statistical life in 2016. The NHTSA/EPA PRIA indicates that fatality costs include fatalities to all occupants of all vehicles involved in collisions, plus any pedestrians.

E. Results for Non-Fatal Crash Costs

Non-fatal crash costs include the value of non-fatal injuries and property damage. Non-fatal crash costs are calculated by applying a scaling factor to the value of fatality crash costs:

$$NonFatalCrashCosts = FatalityCosts\ x\ NonFatalCostsScalar \tag{22}$$

The non-fatal costs scalar is included in Table 11-24 of the NHTSA/EPA PRIA. As seen in the Central Analysis parameters file, the PRIA used 0.39 as the fatalities portion of crash costs factor. The fatalities portion of crash costs factor used by NERA was 0.4323, which is the unweighted fatalities portion of crash costs factor associated with sales and scrappage.

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Appendix J: Petroleum Market Externality Benefits

This appendix provides information on the data and methods used by NERA to assess the external benefits from changes in U.S. fuel consumption on petroleum markets. We focus this appendix on estimates of the "oil security premium"—measured in terms of dollars per barrel—due to changes in the consumption of imported oil and domestic oil. To develop estimates of potential petroleum market external benefits from the CAFE standard alternatives, we combine estimates of the "oil security premium" along with estimates of changes in domestic and imported crude oil due to the alternatives. The basic case we present in the main body of the report is based upon the average values for imported and domestic security premiums contained in a recent (2018) literature review. As sensitivity cases, we show results based upon different estimates of the security premium, including that used in the NHTSA PRIA as well as others provided in the recent literature review.

A. Overview of Methodology to Estimate the Oil Security Premium

1. Potential Factors Included in the Oil Security Premium

Changes in U.S. fuel consumption would lead to changes in the demand for crude oil, which is traded actively on a worldwide market. Interest in quantifying an "oil security premium" grew out of concerns about large U.S. dependence on imported oil and the prominent oil supply disruptions of the 1970s and the resulting "oil price shocks" that were believed to affect the overall U.S. gross domestic product (GDP). In recent years, the United States has become much more self-reliant in producing oil, and recent literature suggests that the U.S. GDP may be less sensitive to world oil price shocks than was previously estimated (Brown 2018).

The following is a summary of three factors that have been identified as potential elements of an "oil security premium." Note that in terms of the benefits assessments in this study, a critical question is whether these effects lead to external impacts, i.e., impacts that are not reflected in market transactions.

1. *U.S. petroleum demand and its effect on global prices and U.S. monopsony power.* An increase in U.S. petroleum demand due to less stringent CAFE standards means that the U.S. would purchase more petroleum. Since global demand is the sum of individual countries' domestic demand, this increase in U.S. demand would translate into an increase in global demand, which would put upward pressure on global petroleum prices. Note, however, that the increased oil price would represent a transfer from consumers to producers rather than an overall cost. There is a related argument that the U.S. is a major oil consumer and can exercise monopsony power, i.e., market power in buying oil on the world market. As noted in Brown (2018), however, the opportunity to exercise market power in buying oil on the world also represents a transfer (i.e., pecuniary externality) rather than a security issue; moreover, such opportunities to exercise market power are dependent upon stable market conditions rather than oil supply disruptions.

2. *Macroeconomic costs of U.S. petroleum consumption (i.e., effect of price shocks).* Changes in U.S. petroleum demand may expose the U.S. economy to risks associated with petroleum supply disruptions, including losses in U.S. GDP. Disruptions to global oil supply can trigger rapid increases in oil prices, which can impose significant costs on an economy, depending on that economy's dependence on petroleum-based products and the availability of substitute energy sources. As noted in the PRIA and in Brown (2018), there is considerable uncertainty regarding the potential significance and continued relevance of economic damages to the U.S. economy from oil supply disruptions and/or oil price shocks, given increased elasticity of oil demand and reduced sensitivity of GDP to oil price shocks. Some recent studies suggest that the potential macroeconomic costs associated with changes to oil prices are likely to be small or trivial.[35] Other studies indicate that there may be somewhat positive economic outcomes associated with oil price shocks.[36] For instance, Nordhaus (2007) and Blanchard & Gali (2010) assert that the U.S. economy expanded after the most recent oil price shock. There is additional recent research, however, suggesting that oil price shocks pose a continued macroeconomic risk, particularly considering the declining sensitivity of petroleum demand to price changes.[37] Despite this uncertainty, this factor constitutes a potential externality that market participants do not include in their demand and supply decisions.

3. *Potential effects of fuel consumption and petroleum imports on U.S. military spending.* Prior studies have suggested that changes in U.S. petroleum demand would affect U.S. military spending to secure the supply of oil imports from potentially unstable regions The PRIA assesses how U.S. military spending has varied historically (1962-2017, specifically) in relation to petroleum consumption and petroleum imports, concluding that there is no relationship between U.S. military spending and either petroleum consumption or petroleum imports.

2. Summary of External Factors Included in Oil Security Premium

The following is a summary of our assessment of the factors that should be included in assessing the size of an oil security premium.

1. Impacts on world oil prices and potential changes in U.S. monopsony power are not external security factors and should not be included in the oil security premium.

2. Potential impacts on U.S. GDP due to oil supply disruptions and oil price shocks are external security factors that should be included in the potential oil security premium.

3. Potential effects on U.S. military spending is not a likely effect of changes in U.S. oil consumption and thus should not be included in the oil security premium.

[35] National Research Council (2009).

[36] Nordhaus (2007; Blanchard and Gali (2010).

[37] Hamilton (2012), Ramey and Vine (2012); Baumeister and Van Robays (2010).

B. Estimates of Oil Security Premiums

This section provides alternative estimates of the oil supply premium based upon the possibility of effects on oil price shocks and GDP impacts. These estimates include the values from the 2018 overview (Brown 2018) that are used in the analysis provided in our main report. Values from the 2018 study are shown for three sets of average estimates based upon the date of the studies used to calculate the average values: (a) older literature; (b) newer literature; and (c) combination of the older and newer literature. As noted below, Brown (2018) recommend use of the combined set of estimates.

1. Security Premiums Used in NHTSA/EPA PRIA

Table J-1 shows the values used by NHTSA/EPA, as included in the CAFE Model documentation and analysis files. To be consistent with other estimates from the literature, the values are changed from $/gallon to $/barrel, based upon a conversion of 42 gallons per barrel.

Table J-1. Changes in Expected Cost of Petroleum Price Shocks from Increased Oil Imports Consumption (2016$/barrel)

Year	2016$/barrel
2017	$8.13
2020	$8.34
2025	$9.04
2030	$9.60
2035	$10.35
2040	$10.35
2045	$10.35
2050	$10.35

Note: For ease of exposition table includes annual values at five year increments. Note that the actual analysis relies on annual-specific values for all relevant years as provided in the CAFE Model parameters file available on the NHTSA website. Values have been converted from barrels to gallons based on an assumed 42 gallons per barrel.
Source: CAFE Model analysis parameters file available on the NHTSA website.

The PRIA notes that these values are based upon those in the previous CAFE RIA (2012), with the dollars adjusted to 2016$. In reviewing the 2012 RIA it seems that this value originated from a 2012 study from Oakridge National Laboratory.[38] The PRIA notes that these values may significantly overstate the security premium based on changes since 2011 in petroleum and related fuel price and projections as well as in the U.S. dependency on imported oil.

2. Security Premium from 2018 Review Study

Table J-2 shows estimates of the security premium provided in the 2018 review article based upon three categorizations of the literature: (a) Old literature, defined as studies before 2010; (b) New literature, defined as studies after 2009[39]; and (c) Combined literature, including both the

[38] Paul N. Leiby, "Estimating the U.S. Oil Security Premium for the 2017-2025 Light -Duty Vehicle GHG/Fuel Economy Rule", Oak Ridge National Laboratory (ORNL), July 15, 2012.
[39] Studies from 2009 and 2010 were grouped into "old" or "new" literature based on the author's judgement. See Brown (2018), p. 174.

Old and New literature. The values represent the security premiums for imported oil and domestic oil. Note that the dollars have been changed from 2015$ in the original to 2016$ used in this study.

Table J-2. Changes in Expected Cost of Petroleum Price Shocks from Increased Oil Consumption (2016$/barrel)

Model	Consumption of Imported Oil	Consumption of Domestic Oil
PVL - O	$7.00	$5.42
PVL - N	$1.66	$1.26
PVL - C	$4.88	$3.74

Note: For ease of exposition table includes annual values at five-year increments. Note that the actual analysis relies on annual-specific values for all relevant years as provided in the CAFE Model parameters file available on the NHTSA website. Values have been converted from barrels to gallons based on an assumed 42 gallons per barrel.
Source: Table 9 from Brown (2018).

C. Results for Petroleum Externality Benefits under Alternative CAFE Standards

This section provides estimates of petroleum externality benefits under the three CAFE alternatives we consider, based upon the oil security premiums described above. Petroleum externality benefits are calculated by multiplying estimates of changes in consumption of imported and domestic oil by estimates of the respective oil security premiums.

1. Primary Results

Table J-3 summarizes estimates of changes in benefits associated with petroleum market externalities due the three alternative CAFE standards we consider. These values correspond to the ones included in the main report. These values are based upon the following information: (1) consumption of domestic and imported oil developed via the MOVES model; and (2) the oil security premiums developed in the 2018 review article; and (3) the values for the Combined studies since they are recommended "to better reflect the uncertainty about the response of world oil markets and the U.S. economy to world oil supply disruptions." (Brown 2018, p. 182).

Table J-3. Petroleum Market Externality Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Petroleum Market Externality Benefits	-$1.3	-$0.8	-$2.2	-$1.3	-$3.9	-$2.3

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.
Source: NERA/Trinity calculations as explained in text.

2. Sensitivity Cases

This section provides three sensitivity cases involving use of alternative values for the oil security premium.

a. NHTSA/EPA PRIA Oil Security Premiums

Table J-4 shows benefit estimates using the oil security premium values used by NHTSA/EPA in the PRIA.

Table J-4. Petroleum Market Benefits Relative to Augural Standards Baseline using NHTSA/EPA PRIA Estimates of Oil Price Shock Externalities (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Petroleum Market Externality Benefits	-$2.4	-$1.4	-$4.1	-$2.4	-$7.4	-$4.4

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.

Source: NERA/Trinity calculations as explained in text.

b. 2018 Review Article Older Studies

Table J-5 shows benefits estimates using the oil security premium values taken from the older studies in the 2018 review article.

Table J-5. Petroleum Market Externality Benefits Relative to Augural Standards Baseline using "Old Literature" Values from Brown (2018) (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Petroleum Market Externality Benefits	-$1.8	-$1.1	-$3.1	-$1.9	-$5.6	-$3.3

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.

Source: NERA/Trinity calculations as explained in text.

c. 2018 Review Article Newer Studies

Table J-6 shows benefits estimates using the oil security premium values taken from the new studies in the 2018 review article.

Table J-6. Petroleum Market Externality Benefits Relative to Augural Standards Baseline using "New Literature" Values from Brown (2018) (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Petroleum Market Externality Benefits	-$0.4	-$0.3	-$0.7	-$0.4	-$1.3	-$0.8

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.

Source: NERA/Trinity calculations as explained in text.

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Appendix K: Greenhouse Gas Emission Benefits

This appendix provides information on the data and methods developed by NERA to assess the benefits related to changes in greenhouse gas (GHG) emissions benefits due to the alternative CAFE standards. We focus this appendix on the monetary value of GHG emissions, which is based on the estimated future stream of damages from a one metric ton increase in GHG emissions. This discounted value is referred to as the Social Cost of Carbon (SCC), a value that varies over time. For our primary set of SCC values, we rely upon the domestic SCC values developed by EPA in the Regulatory Impact Analysis (RIA) for the Clean Power Plan (CPP) Review; these domestic values were used by NHTSA/EPA in the PRIA.[40] As a sensitivity case, we show results using the global SCC values that are reported by EPA in the CPP Review RIA.

A. Overview of Methodology to Develop Social Cost of Carbon Values

SCC values were first developed by the Interagency Working Group on Social Cost of Carbon (IWG) in 2010 (IWG 2010). The IWG issued technical updates in 2013 (IWG 2013), 2015 (IWG 2015) and 2016 (IWG 2016). The estimates developed by the IWG are based upon results from three integrated assessment models (IAMs)—referred to as PAGE, FUND, and DICE—using various assumptions regarding future parameters that affect damages, including income and population growth. The values developed by EPA in the CPP Review RIA rely upon results from the same three IAMs.

1. Use of Results from Integrated Assessment Models to Develop SCC Values by Discount Rate

IAMs are complex models of the global climate and economy that translate CO_2 emissions into changes in the climate system (most notably, temperature increases), and then translate these changes in the climate system into various types of economic damages, summarized by losses in gross domestic product (GDP). Since these models consider the damages over the atmospheric lifetime of a unit increase in CO_2 emissions (i.e., 1 metric ton), the results are sensitive to many factors such as the probability distribution for equilibrium climate sensitivity, socioeconomic, population, and emissions growth trajectories; and discount rate assumptions.

The PRIA provides a summary of the methodology used by EPA to develop SCC values. This methodology includes the following computational steps to determine a social cost of carbon estimate for a given year t:

1. Calculate the temperature effects and (consumption-equivalent) damages in each year from the baseline path of CO_2 emissions;
2. Adjust the model to reflect an additional unit of CO_2 emissions in year t;

[40] See NERA (2018) for information on alternative estimates of the social costs of carbon and effects on the PRIA net benefit estimates.

3. Recalculate the temperature effects and damages expected in all years beyond t resulting from this adjusted path of emissions, as in step 1;

4. Subtract the damages computed in step 1 from those in step 3 in each model period and discount the resulting path of marginal damages back to the year of the assumed unit change in CO_2 emissions (pp. 1106-1107).

For each discount rate, these four steps are repeated for each of the three IAMs with each of the five socio-economic and emissions trajectories. This results in 10 different distributions of annual SCC estimates for each of the three discount rates that are used by EPA in the CPP Review RIA (2.5%, 3% and 7%). These distributions are equally weighted and combined to produce a single set of annual SCC values for a given discount rate.

2. Use of Values Based on Domestic Rather than Global Damages

The values reported by NHTSA/EPA in the PRIA are domestic values, i.e., they reflect IAM estimates for domestic damages rather than global damages. Moreover, the values are reported for two of the three discount rates, 3% and 7%. The domestic values are obtained directly in the PAGE and FUND models; for the DICE model (which models only global damages), EPA approximates the domestic damages as 10 percent of the global values.

B. Social Cost of Carbon Values

This section provides the SCC values we used, including the domestic SCC values as well as the global values developed by EPA in the CPP Review RIA.

1. Domestic SCC Values

Table K-1 shows the domestic SCC values developed by EPA in the CPP Review RIA, using both 3% and 7% discount rates. As noted, these values were used NHTSA/EPA in the PRIA. We use these values as the basis for the estimates of GHG benefits in the main report (see Table 45).

Table K-1. EPA Domestic Social Costs of Carbon Values (2016$/metric ton)

	Discount Rate	
Year	3%	7%
2017	$6	$1
2020	$7	$1
2025	$7	$1
2030	$8	$1
2035	$9	$2
2040	$9	$2
2045	$10	$2
2050	$11	$2

Note: Values rounded to nearest whole dollar. For ease of exposition table includes annual values at five-year increments. Note that the actual analysis relies on annual-specific values for all relevant years as provided in the CAFE Model parameters file available on the NHTSA website.

Source: Table 8-24 from NHTSA/EPA PRIA; CAFE Model analysis parameters file available on the NHTSA website.

2. Global SCC Values

OMB Circular A-4 states that when an agency "evaluate[s] a regulation that is likely to have effects beyond the borders of the United States, these effects should be reported separately" (page 15 of OMB Circular A-4). The RIA for the CPP Review notes that this OMB guidance is relevant to the valuation of GHG emissions, since these pollutants contribute to damages around the world regardless of the location from which they are emitted (EPA 2017, p. 168).

We develop global SCC values based on information in the CPP Review RIA. Note that the CPP Review RIA does not provide a full list of their global SCC values for all years and discount rates. EPA does provide the following information on their global SCC results, which allows us to develop estimates of global SCC values for the years in our analysis (2017 to 2050).

- The domestic SCC estimates are approximately 14 percent of the global SCC estimates using a 3 percent discount rate;
- The domestic SCC estimates are approximately 19 percent of the global SCC estimates using a 7 percent discount rate;
- The average global SCC estimate across all the model runs for emissions occurring over 2020-2030 ranges from \$44 to \$53 per metric ton of CO_2 emissions (2011\$) using a 3 percent discount rate (2011\$); and
- The average global SCC estimate across all the model runs for emissions occurring over 2020-2030 ranges from \$5 to \$7 per metric ton of CO_2 emissions (in 2011 dollars) using a 7 percent discount rate.

Based on this information we developed a set of global SCC estimates based on discount rates of 3 percent, and 7 percent. These values are summarized in Table K-2.

Table K-2. Estimates of Global Social Costs of Carbon Values (2016\$/metric ton)

	Discount Rate	
Year	**3%**	**7%**
2015	\$44	\$4
2020	\$47	\$5
2025	\$51	\$6
2030	\$56	\$7
2035	\$61	\$8
2040	\$66	\$10
2045	\$71	\$11
2050	\$76	\$13

Note: Values rounded to nearest whole dollar. For ease of exposition table includes annual values at five-year increments.

Source: EPA (2017) and NERA assumptions as explained in text; CAFE Model analysis parameters file available on the NHTSA website.

C. Results for Greenhouse Gas Emissions Benefits under Alternative CAFE Standards

This section provides estimates of the GHG benefits under the three CAFE alternatives we evaluate, based upon the SCC values described above, including the domestic SCC values (which are the basic estimates used in the main report) and the global SCC values (which represent a sensitivity case). The results include the GHG emissions impact of the alternative standards on both (a) tailpipe emissions developed using the MOVES model as summarized in Appendix F and (b) upstream emissions developed based on applying the upstream emissions factors used by NHTSA/EPA in the PRIA to our estimates of changes in fuel consumption as summarized in Figure 6.

1. Results Based on Domestic Social Cost of Carbon Values

Table K-3 provides our estimates of domestic CO_2 reduction benefits for each scenario relative to the augural standards baseline, based upon Trinity estimates of changes in upstream emissions. Note that these are same values reported in Table 45.

Table K-3. Domestic CO_2 Reduction Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
GHG Damage Reduction Benefits	-$1.6	-$0.2	-$2.9	-$0.3	-$7.1	-$0.7

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. GHG damage reduction benefits values include benefits associated CO_2, as well as other GHG pollutants, which have been converted to CO_{2eq}.

Source: NERA/Trinity calculations as explained in text.

2. Sensitivity Case Using Global SCC Values

Table K-4 provides our estimates of global CO_2 reduction benefits, which we calculate using the SCC values included in Table K-2, for each scenario relative to the augural standards baseline

Table K-4. Global CO_2 Reduction Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
GHG Damage Reduction Benefits	-$11.7	-$0.9	-$20.6	-$1.5	-$50.8	-$3.8

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. GHG damage reduction benefits values include benefits associated CO_2, as well as other GHG pollutants, which have been converted to CO_{2eq}.

Source: NERA/Trinity calculations as explained in text.

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Appendix L: Criteria Pollutant Emissions Benefits

This appendix provides information on the data and methods developed by NERA to assess the benefits due to changes in criteria pollutant benefits due to the alternative CAFE standards. We focus this appendix on the monetary value of three of the criteria pollutants—particulate matter ($PM_{2.5}$), nitrogen oxides (NO_x), and sulfur dioxide (SO_2)—based upon information provided in a February 2018 EPA Document entitled "Technical Support Document Estimating the Benefit per Ton of Reducing $PM_{2.5}$ Precursors from 17 Sectors" (EPA 2018).[41] This document provides estimates of the benefits per ton of reducing these three pollutants in 17 sectors, including on-road mobile sources and refineries, based upon their roles as precursors of $PM_{2.5}$. Note that the monetary values we develop exclude various welfare effects including: (a) effects other than the health effects of exposure to $PM_{2.5}$ from these three criteria pollutants; and (b) effects due to carbon monoxide (CO), though these emissions impacts are included in Chapter III.

To develop benefits estimates based upon the benefit-per-ton estimates, we rely upon Trinity's estimates of the changes in (a) tailpipe emissions due to the three CAFE alternatives as reflected in the MOVES results as summarized in Appendix F and (b) upstream emissions developed based on applying the upstream emissions factors used by NHTSA/EPA in the PRIA to our estimates of changes in fuel consumption due to the alternative standards as summarized in Figure 6.

A. Overview of Methodology to Develop Benefit-per-Ton Values

The benefit-per-ton method rests on the premise that the conceptually correct measure of the value of reducing a ton of pollutant is equal to the value of the reduced damages from reducing that ton (assuming no binding cap-and-trade program or other equivalent method for internalizing the damages from emissions). Potential damages can include effects on health, visibility, agriculture, and other effects.

1. Overview of Steps in Developing Benefit-per-Ton Values

The benefit-per-ton approach is illustrated in Figure L-1 as a series of steps involving different modeling and estimation procedures.

[41] We note that NERA has not evaluated the underlying studies behind the dollar benefit values in the February 2018 EPA $PM_{2.5}$ Technical Support Document and thus our use of the values does not constitute confirmation of the validity or accuracy of the benefit estimates.

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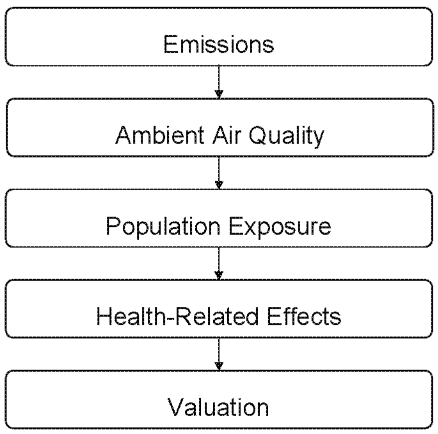
Figure L-1. Steps in Estimating Environmental Benefits from Reduction in Criteria Pollutants



The following are brief overviews of these steps.

- *Effects of emissions on air quality.* The criteria air emissions contribute to ambient concentrations of various criteria pollutants, notably $PM_{2.5}$ and ozone. Ambient $PM_{2.5}$ concentrations arise from $PM_{2.5}$ particles that are emitted directly and from small-diameter particulates that are formed by chemical reactions in the air involving NO_x and SO_2. Ozone is formed by complicated atmospheric photochemical reactions involving NO_x, VOC, and sunlight. The source of emissions (e.g., stationary versus mobile source) can have a significant effect on pollutant dispersion and thus on the effects on air pollutant concentrations.
- *Effects of air quality on population exposure*. The benefits associated with decreases in ambient concentrations of $PM_{2.5}$ and ozone depend on the number of people exposed to the increased concentrations. Decreases in $PM_{2.5}$ and ozone concentrations will have larger health benefits in populous areas than in rural areas. Other effects, such as possible reductions in agricultural yields, also depend on (non-human) exposure.
- *Effects of population exposure on various adverse effects.* The relationship between increased exposure and increased health and welfare effects is a crucial element of the benefit-per-ton approach to assessing environmental costs. For health effects, such relationships typically are measured with concentration-response ("C-R") functions, which are based upon statistical studies from the epidemiology literature.[42] "C-R functions are equations that relate the change in the number of individuals in a population exhibiting a 'response' … to a change in pollutant concentration experienced by that population" (U.S. EPA 1999, p. 52). The "responses" described by C-R functions are often referred to as health endpoints. C-R functions translate changes in the numbers of people exposed to

[42] In the case of non-health effects (such as effects on agricultural yield), these relationships are typically called "exposure-response" functions.

various ambient pollutant concentrations into changes in health effects. U.S. EPA notes that "epidemiological studies, by design, are unable to definitively prove a causal relationship between an exposure and a given health effect; they can only identify associations or correlations between exposure and the health outcome" (U.S. EPA 1999, p. D-7). Nonetheless, such studies generally provide the primary basis for developing C-R functions.

- *Valuation of health and other welfare changes.* Once increased incidences of health effects (or other effects, to the extent that they are considered) are determined, the dollar values of those effects must be estimated to generate estimated benefit values for a reduction in direct air emissions. Over the past several decades, economists and other researchers have devised various methods for estimating how much people are willing to pay to reduce risks to health, including the risk of premature mortality. Some of the methods rely upon the implicit tradeoffs that individuals make in various decisions; for example, statistical models have been used to estimate the increased wages that workers demand in riskier occupations. Other methods rely upon direct surveys of representative individuals.

2. Limitations of Using National Benefits per Ton Values

The benefit-per-ton estimates developed in the documents used in this study are national average estimates. But as the overview of the steps involved in their estimation makes clear, the actual benefits are highly dependent upon location. Benefits can vary greatly depending on the regional meteorology, characteristics of emissions sources, and susceptibility of local populations to "adverse health outcomes" (Fann et al. 2009, p. 170). This feature contrasts to the case of GHG emissions, which have the same effects regardless of where they are emitted. Thus, the estimates of changes in benefits due to changes in emissions of criteria pollutants that are provided in this study should be viewed as speculative for various reasons, including the fact that they do not account for the locations of the changes in emissions due to the alternative CAFE standards.

B. Benefit-per-Ton Values

This section provides alternative benefit-per-ton values, including the values based upon the 2018 EPA $PM_{2.5}$ Technical Support Document that are the primary values used in this study. These values are shown for three sectors: (a) on-road mobile sources; (b) area sources; and (c) refinery. We begin with a table showing values used by NHTSA/EPA in the PRIA and by EPA in the 2012 RIA. The values used by NHTSA/EPA in the PRIA are used in sensitivity analyses provided at the end of this appendix.

1. Benefit-per-Ton Values in NHTSA/EPA PRIA

NHTSA/EPA notes in the PRIA (2018) that they use benefit-per-ton values from the 2012 RIA "Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards" (hereafter, "2012 RIA") adjusted to 2016 dollars. Table L-1 shows these benefit-per-ton values. These benefit-per-ton values are based on human health benefits associated with reductions in $PM_{2.5}$ exposure—that is, they do not estimate health benefits relating to ozone precursors, or those directly from NO_x or SO_2 (which are included as precursors to $PM_{2.5}$) (EPA 2012, p. 6-99). According to EPA, these estimates are derived from health impact functions used in the 2006 PM NAAQS RIA.[43]

Table L-1. PRIA Benefit-per-Ton Values (2016$/metric ton)

Pollutant	2016$/mt
Volatile Organic Compounds (VOCs)	$2,000
Nitrogen Oxides	$8,200
Particulate Matter	$371,100
Sulfur Dioxide	$48,000

Source: CAFE Model analysis parameters file available on the NHTSA website.

2. Benefit-per-Ton Values in 2012 EPA RIA

The 2012 RIA (in Table 6.3-14 of the 2012 RIA provides benefit-per-ton numbers as a range, with values differing by emissions source (i.e., mobile-source and stationary), year, discount rate, and epidemiology study (i.e., Pope et al., 2002 and Laden et al., 2006). Table L-2 and Table L-3 show the values, with results from the two epidemiology studies weighted equally (as EPA indicates is appropriate). Note that EPA does not provide separate SO_2 values by emissions source (i.e., provides a single set of values for both mobile-source and stationary). EPA also does not include estimates of the benefit-per-ton value for VOCs.

Table L-2. 2012 EPA RIA Benefit-per-Ton Values for Mobile-Source Emissions (2016$/metric ton)

	3% Discount Rate			7% Discount Rate		
Year	$PM_{2.5}$	SO_2	NO_X	$PM_{2.5}$	SO_2	NO_X
2017	550,000	59,000	10,000	500,000	53,000	8,900
2020	580,000	62,000	11,000	530,000	56,000	9,400
2025	640,000	68,000	12,000	580,000	61,000	11,000
2030	700,000	73,000	13,000	630,000	66,000	12,000
2035	770,000	79,000	14,000	690,000	71,000	13,000
2040	850,000	85,000	15,000	750,000	77,000	14,000
2045	920,000	92,000	17,000	810,000	83,000	15,000
2050	1,000,000	98,000	18,000	870,000	89,000	16,000

Note: Values in 2016$/metric ton. Dollar year conversions based on implicit GDP deflator information from BEA.

Source: EPA RIA (2012); NERA calculations as explained in text; BEA (2018).

[43] The 2006 PM NAAQS RIA uses premature mortality related coefficients from epidemiology studies that examine two major population cohorts: the American Cancer Society cohort (Pope et al., 2002) and the Harvard Six Cities cohort (Laden et al., 2006). (EPA 2012, p. 6-103)

Table L-3. 2012 EPA RIA Benefit-per-Ton Values for Stationary-Source Emissions (2016$/metric ton)

	3% Discount Rate			7% Discount Rate		
Year	$PM_{2.5}$	SO_2	NO_X	$PM_{2.5}$	SO_2	NO_X
2017	450,000	59,000	9,600	410,000	53,000	8,900
2020	480,000	62,000	10,000	440,000	56,000	9,300
2025	520,000	68,000	11,000	470,000	61,000	10,000
2030	560,000	73,000	12,000	510,000	66,000	11,000
2035	600,000	79,000	14,000	550,000	71,000	12,000
2040	650,000	85,000	15,000	590,000	77,000	13,000
2045	700,000	92,000	16,000	630,000	83,000	14,000
2050	740,000	98,000	17,000	670,000	89,000	15,000

Note: Values in 2016$/metric ton. Dollar year conversions based on implicit GDP deflator information from BEA.

Source: EPA RIA (2012); NERA calculations as explained in text; BEA (2018).

3. Benefit-per-Ton Values in EPA (2018)

Table L-4 and Table L-5 shows estimates of the benefits-per-ton values for the three pollutants included in EPA (2018) over time. The values are based upon EPA's 2017 version of its environmental Benefits Mapping and Analysis Program—Community Edition (BenMAP-CE) tool. As discussed below, EPA TSD (2018) includes a discussion of the limitations and uncertainties associated with application of these estimates. The tables show results for tailpipe emissions and upstream emissions for two discount rates. Benefit-per-ton estimates for each pollutant and discount rate were developed based on the average benefit-per-ton value across the two epidemiological studies reported in EPA (2018).

For tailpipe emissions, we rely on the values reported in the EPA $PM_{2.5}$ TSD (2018) for the "on-road mobile sources" sector. For upstream emissions, whose activities span multiple sectors, we use a weighted-average based on the "On-Road Mobile Sources" (25%), "Aircraft, Locomotives and Marine Vessels[44]" (25%), and "Refineries" (50%) sectors. Based on our review of the upstream emissions factors used by NHTSA, we conclude that a combination of these sectors would most accurately capture the underlying fuel development and transportation, distribution, and storage activities. Note that the EPA (2018) includes values for 2016, 2020, 2025, and 2030 only. We interpolate linearly between each chronological pair of years (e.g., 2020 and 2025) to develop appropriate estimates for intermediate years. For years beyond 2030, we extrapolate based on the linear trend from 2025 to 2030. Note that EPA (2018) does not include estimates of the benefit-per-ton value for VOCs.

[44] EPA (2018) notes that due to an emissions processing error, the current values for "aircraft, locomotives, and marine vessels" sector omit aircraft omissions (p. 5)

Table L-4. EPA (2018) Benefit-per-Ton Values for Tailpipe Emissions (2016$/metric ton)

	3% Discount Rate			7% Discount Rate		
Year	**$PM_{2.5}$**	**SO_2**	**NO_X**	**$PM_{2.5}$**	**SO_2**	**NO_X**
2017	670,000	36,000	14,000	600,000	32,000	13,000
2020	690,000	38,000	15,000	620,000	34,000	13,000
2025	740,000	41,000	15,000	680,000	38,000	14,000
2030	810,000	47,000	17,000	730,000	41,000	15,000
2035	880,000	52,000	18,000	790,000	45,000	17,000
2040	950,000	57,000	19,000	840,000	49,000	18,000
2045	1,000,000	62,000	21,000	900,000	52,000	19,000
2050	1,100,000	67,000	22,000	960,000	56,000	21,000

Note: Values in 2016$/metric ton. Dollar year conversions based on implicit GDP deflator information from BEA. Tailpipe emissions benefit-per-ton values based on the "On-Road Mobile-Source" values from EPA (2018). For ease of exposition, values rounded to two significant figures.

Source: EPA Technical Support Document (EPA 2018); BEA (2018); NERA calculations as explained in text.

Table L-5. EPA (2018) Benefit-per-Ton Values for Upstream Emissions (2016$/metric ton)

	3% Discount Rate			7% Discount Rate		
Year	**$PM_{2.5}$**	**SO_2**	**NO_X**	**$PM_{2.5}$**	**SO_2**	**NO_X**
2017	570,000	110,000	13,000	510,000	97,000	12,000
2020	590,000	110,000	13,000	530,000	100,000	12,000
2025	640,000	120,000	14,000	580,000	110,000	13,000
2030	690,000	140,000	16,000	620,000	120,000	14,000
2035	750,000	150,000	17,000	670,000	140,000	16,000
2040	810,000	160,000	18,000	720,000	150,000	17,000
2045	860,000	180,000	20,000	770,000	160,000	18,000
2050	920,000	190,000	21,000	820,000	170,000	20,000

Note: Values in 2016$/metric ton. Dollar year conversions based on implicit GDP deflator information from BEA. Upstream emissions benefit-per-ton values based on a weighted-average of the "On-Road Mobile Sources" (25%), "Aircraft, Locomotives, and Marine Vessels" (25%), and "Refineries" (50%) sectors from EPA (2018). For ease of exposition, values rounded to two significant figures.

Source: EPA Technical Support Document (EPA 2018); BEA (2018); NERA calculations as explained in text.

The benefit-per-ton values from EPA's 2018 $PM_{2.5}$ TSD differ from those used by NHTSA in the PRIA along several dimensions.

1. *More recent demographic data.* The values included in EPA (2018) are based on the latest (2017) version of EPA's environmental BenMAP-CE.

2. *Updated epidemiology studies.* EPA (2018) incorporates updated morbidity and mortality studies, i.e., Krewski et al. (2009) and Lepeule et al. (2012).

3. *Discount rates.* EPA (2018) includes separate valuations estimates for 3 percent and 7 percent discount rates. The NHTSA/EPA PRIA valuation parameters do not differ by discount rate.

4. *Tailpipe vs Upstream*. EPA (2018) includes separate valuations estimates for emissions in different sectors including three sectors that seem most relevant for the CAFE analysis (on-road mobile, area, and refinery).

5. *Annual values*. EPA (2018) provides annual benefit-per-estimates for the relevant pollutants and discount rates. The NHTSA/EPA PRIA benefit-per-ton values do not vary by year.

As noted, we have not developed independent assessments of the validity of the information that lies behind the benefit-per-ton values included in EPA (2018) and the BenMAP-CE tool.

C. Results for Criteria pollutant Benefits under Alternative CAFE Standards

This section provides estimates of criteria pollutant benefits under the three CAFE alternatives we consider, based upon the benefit-per-ton values described above. Emissions reduction benefits are calculated by multiplying estimates of changes in emissions by estimates of the respective benefit-per-ton values. In calculating the primary benefits estimates, we rely on (1) tailpipe emissions developed via the MOVES model; (2) upstream emissions based on the upstream factors used by NHTSA/EPA in the PRIA developed via the GREET model; and (3) benefit-per-ton values developed in EPA (2018). Note that since EPA (2018) does not include benefit-per-ton estimates for VOCs, we develop monetary estimates of the criteria pollutant reduction benefits for VOCs based on the value used in the PRIA as reported in Table L-1. As a sensitivity case, we use the benefit-per-ton values used in the PRIA.

1. Primary Results

Table L-6 summarizes estimates of changes in benefits associated with criteria pollutant reductions due the three alternative CAFE standards we consider. These values correspond to the ones included in the main report.

Table L-6. Criteria Pollutant Emissions Reductions Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
NO_x Damage Reduction Benefits	$0.0	$0.0	$0.1	$0.1	$0.0	$0.0
VOC Damage Reduction Benefits	$0.0	$0.0	-$0.1	$0.0	-$0.1	-$0.1
$PM_{2.5}$ Damage Reduction Benefits	-$0.4	-$0.2	-$0.8	-$0.5	-$1.7	-$1.0
SO_2 Damage Reduction Benefits	-$2.0	-$1.2	-$3.4	-$2.0	-$6.1	-$3.6
Total	**-$2.4**	**-$1.4**	**-$4.2**	**-$2.5**	**-$8.0**	**-$4.7**

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. Values may not sum to totals due to rounding.

Source: NERA/Trinity calculations as explained in text.

2. Sensitivity Case using NHTSA/EPA PRIA Benefit-per-Ton Values

Table L-7 shows benefit estimates using the benefit-per-ton values used by NHTSA/EPA in the PRIA as summarized in Table L-1 rather than the benefit-per-ton values we rely on from EPA (2018) as summarized in Table L-4 and Table L-5.

Table L-7. Criteria Pollutant Emissions Reductions Benefits Relative to Augural Standards Baseline using NHTSA/EPA PRIA Benefit-per-Ton Values (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
NO_x Damage Reduction Benefits	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
VOC Damage Reduction Benefits	$0.0	$0.0	-$0.1	$0.0	-$0.1	-$0.1
$PM_{2.5}$ Damage Reduction Benefits	-$0.3	-$0.1	-$0.5	-$0.3	-$1.0	-$0.6
SO_2 Damage Reduction Benefits	-$0.7	-$0.4	-$1.2	-$0.7	-$2.1	-$1.3
Total	**-$1.0**	**-$0.6**	**-$1.7**	**-$0.9**	**-$3.2**	**-$1.9**

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion. Values may not sum to totals due to rounding.

Source: NERA/Trinity calculations as explained in text.

3. Limitations and Uncertainties

EPA (2018, pp. 25-27) discusses the limitations and uncertainties of the national benefit-per-ton values it reports. The following is a summary of the issues raised.

- *Data sources*. "The analysis includes many data sources as inputs, including emissions inventories, air quality data from models (with their associated parameters and inputs) population data, health estimates from epidemiology studies, and economic data for monetizing benefits. Each of these inputs may be uncertain and would affect the benefits estimate. When the uncertainties from each stage of the analysis are compounded, small uncertainties can have large effects on the total quantified benefits."

- *Equality of potency of all fine particles.* "In this analysis we assume that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because $PM_{2.5}$ produced via transported precursors emitted from EGUs may differ significantly from direct $PM_{2.5}$ released from other industrial sources. However, the scientific evidence is not yet sufficient to allow differentiation of effect estimates by particle type.

- *Linear down to lowest air quality level.* "We also assume that the health impact function for fine particles is linear down to the lowest air quality levels modeled in this analysis. Thus the estimates include health benefits from reducing fine particles in areas with varied concentrations of $PM_{2.5}$, including regions that are in attainment with fine particle standard."

- *Geographic patterns.* "It is also important to note that the monetized benefit per ton estimates used here reflect specific geographic patterns of emissions and specific air quality benefit modeling assumptions. Great care should be taken in applying these estimates to emission reductions occurring in any specific location, as these are all based on national emission reduction assumptions and therefore represent an average benefit per ton over the entire United States. The benefit per ton for emission reductions in specific locations may be very different from the estimates presented here."
- *Combinations of reductions.* "In addition, estimates do not capture important differences in marginal benefit per ton that may exist due to different combinations of reductions (i.e., all other sectors are held constant) or nonlinearities within a particular pollutant (e.g., non-zero second derivatives with respect to emissions)."

D. References

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NERA
ECONOMIC CONSULTING

Trinity Consultants

NERA Economic Consulting
11th Floor, 200 Clarendon Street
Boston, Massachusetts 02116
Tel: 1 (617) 927-4500
www.nera.com

Trinity Consultants
3301 C Street, Suite 400
Sacramento, CA 95816
Tel: + 1 916 444-6666
www.trinityconsultants.com

Message

From:	Charmley, William [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=FB1828FB00AF42FFB68B9E0A71626D95-CHARMLEY, WILLIAM]
Sent:	12/14/2018 5:59:01 PM
To:	Harrison, David [David.Harrison@NERA.com]
CC:	CNevers@autoalliance.org
Subject:	A second question on the NERA study

David,

My staff and I had another question regarding the NERA study on the SAFE NPRM done for the Auto Alliance.

We are trying to understand why the NERA study estimated in the net societal benefits for fuel savings is much lower then what was projected in the Notice of Proposed Rulemaking.

In the NPRM, NHTSA estimated the pre-tax fuel savings for society for the proposal to be over $100 billion. In the NERA report, the reported "Valuation of Fuel Cost Savings" is $51.3 billion with a 3% discount rate and $38.0 billion with a 7% discount rate (shown in Table 40 on page 55, which I copied into this email). Those values include the taxes, so the "pre-tax" values would be lower than these values.

On page 55 of the NERA report, under Section B., there is the following statement:

> *"Our methodology for estimating the benefit consumers receive from the improved fuel efficiency includes changes in consumers' valuation of prospective fuel savings from improvements."*

We understand that in the context of a consumer choice model, it would be appropriate to consider what the consumers valuation of fuel savings are. But in the Net Societal Benefits, we would have thought that all of the pre-tax fuel savings would be included.

Can you let us know how NERA looked at this issue, and are we interpreting this correctly – that in the Net Societal Benefits, the NERA analysis does not include all of the pre-tax fuel savings, but something less than all of it?

Thanks
Bill

Table 40. Fuel Economy Benefits Relative to Augural Standards Baseline (billions of 2016$)

	Scenario 8		Scenario 5		Scenario 1	
	3%	7%	3%	7%	3%	7%
Valuation of Fuel Cost Savings	-$16.7	-$12.4	-$28.9	-$21.3	-$51.3	-$38.0
Rebound Mobility Benefit	-$9.7	-$5.8	-$17.4	-$10.3	-$31.0	-$18.5
Refueling Time Benefit	-$1.6	-$0.9	-$2.7	-$1.6	-$4.9	-$2.9
Benefits of Fuel Economy Changes	**-$28.0**	**-$19.1**	**-$49.0**	**-$33.3**	**-$87.2**	**-$59.5**

Note: Present values calculated as of January 1, 2017 using 3 percent and 7 percent discount rates for costs/benefits incurred over the 2017-2050 analysis period. The values include effects for model year vehicles up to MY 2029. All values relative to augural standards baseline. All values in billions of 2016 dollars, rounded to the nearest $0.1 billion.

Source: NERA/Trinity calculations as explained in text.

From: Charmley, William
Sent: Friday, November 30, 2018 3:55 PM
To: Harrison, David <David.Harrison@NERA.com>
Subject: RE: Question on the NERA study

David –

Thanks for getting back to me, I appreciate it.

Best regards,
Bill

From: Harrison, David <David.Harrison@NERA.com>
Sent: Friday, November 30, 2018 10:15 AM
To: Charmley, William <charmley.william@epa.gov>
Cc: Chris Nevers <CNevers@autoalliance.org>
Subject: RE: Question on the NERA study

Hi Bill,

Good to hear from you. The gasoline price projections we used are from AEO 2017, based upon the information in the CAFE model.

Please give my best to others in Ann Arbor.

Best,

== Dave

David Harrison, Ph.D., Managing Director
NERA

ECONOMIC CONSULTING
Tel: +1 617 927 4512
david.harrison@nera.com

From: Charmley, William <charmley.william@epa.gov>
Sent: Thursday, November 29, 2018 4:36 PM
To: Harrison, David <David.Harrison@NERA.com>
Cc: Chris Nevers <CNevers@autoalliance.org>
Subject: Question on the NERA study

Dear David –

I hope all is going well with you and your colleagues out in Cambridge.

My staff were reviewing with me today the NERA report conducted for the Auto Alliance "Evaluation of Alternative Passenger Car and Light Truck Corporate Average Fuel Economy (CAFE) Standards for Model Years 2021-2026" which was submitted by the Alliance as part of their comments on the recent DOT/EPA proposal for fuel economy and GHG standards for light-duty vehicles.

At this point I we have one clarifying question that I am hoping you can answer for us, and that it, what gasoline fuel price projections did NERA use for the NERA analysis? In particular, in the Table 48 Net Benefits projections on page 61, which fuel price projection forecast was used? This is the same information presented in Table ES-3 in the Executive Summary.

We see discussion in the report of EIA's AEO 2017 projections, and also the 2018 IHS Markit Retail Gasoline Price Forecast. Were one of these used in the NERA modeling to detailed in the report, and in particular the analysis presented in the Tables ES-3 and Table 48?

Thank you for your help on this.

Best regards,
Bill

Bill Charmley
Director
Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

National Vehicle and Fuel Emissions Laboratory
2000 Traverwood Drive
Ann Arbor, MI 48105

desk ph. 734-214-4466
cell ph. 734-545-0333
e-mail: charmley.william@epa.gov